Draft Final Report

Assignment Title: First Order Geospatial Least Cost Electrification Plan

Assignment Country: Malawi (MWI)

Selection Number: 1251553

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Acronyms and Abbreviations

Acronym / Abbreviation	Full Name	Web URL
CARD	Churches Action in Relief and Development	https://actalliance.org/about/members/churches-action-in-relief-and-development-card/
DOEA	Department of Energy Affairs	www.malawi.gov.mw
EGENCO	Electricity Generation Company (Malawi) Ltd.	www.egenco.mw
ESCOM	Electricity Supply Company of Malawi Ltd.	www.escommw.com
FISD	FISD Limited	http://www.fisdltd.com/
HRSL	High Resolution Settlement Layer	ciesin.columbia.edu/data/hrsl/
MERA	Malawi Energy Regulatory Authority	www.meramalawi.mw
MAREP	Malawi Rural Electrification Programme	
MP	Millennium Promise	www.millenniumpromise.org/
OFID	OPEC Fund for International Development	http://www.ofid.org
PA	Practical Action	https://practicalaction.org
NES	National Electrification Strategy	
NSO	National Statistics Office of Malawi	www.nsomalawi.mw
SG	Scottish Government	
UNICEF	United Nations Children's Fund	www.unicef.org/malawi/
UNDP	United Nations Development Programme	www.mw.undp.org
WB	World Bank	www.worldbank.org/en/country/malawi

1 Executive Summary

This is the Draft Final report for the project First Order Geospatial Least Cost Electrification Plan for Malawi. This Executive Summary describes results of the analysis and key conclusions regarding electrification planning. The project's objectives have been: to undertake a GIS mapping of population settlement patters nationwide with attention to proximity to existing medium voltage (MV) grid infrastructure; to develop first order estimates of the unit capex for connectivity based in grid extensions; and to identify select off-grid / mini-grid sites where grid is unlikely to reach in the near term.

The purpose of the analysis presented here is to inform the subsequent design and detailing to follow of Malawi's program to achieve universal access per SE4ALL. This includes identification of near-term targets for grid access particularly through expanding access by densification/intensification of connections to beneficiaries settled in areas near existing grid infrastructure and thus marked by low unit capex. Observations and recommendations related to each of these objectives are presented in this report.

- **The overwhelming majority of Malawi's current and future population lives close to existing ESCOM MV grid lines.** Over 60% of the country's people (~12 million) reside within 2.5 km of existing grid, and more than 80% (~15 million) reside within 5 km. This applies all three of Malawi's Regions and will persist as population grows.
- **Major access gains can be achieved by "intensification": connecting those in range of existing transformers.** An estimated 1.1 million households reside within 500 m of existing ESCOM transformers and 1.5 million within 1 km. Of these, only ~300,000 are connected, 20-30% of the possible total.
- **A geospatial analysis prioritizing MV grid extension recommends a set of 109 "high" or "very high" priority locations with over 100,000 households.** Priority in this analysis is based on settlement size and distance from existing ESCOM grid lines.
- **Capex for grid connections can be reduced at least 25 percent under best practices of a national electrification plan.** This is accomplished largely by increasing coverage near the grid, distributing costs for the MV "backbone" among more connections.
- **Off-grid electrification will, in the near term, focus on "pre-electrification" for sites that will likely wait several years for grid access.** Particularly in areas distant from the

grid, where grid extension will take at least five years, off-grid systems can offer basic electricity services.

While this "first-order" geospatial analysis focused primarily on prioritization of grid and off-grid connections, there are additional insights to be gained from a geospatial approach, both from a much more localized analysis using the same dataset and approach, or an additional national analysis using algorithmically optimized least-cost planning techniques. Therefore, it is important to consider the practical implications related to using the results of this "first order" analysis and associated datasets for more detailed recommendations and analysis, including possible next steps.

- **Greater detail for specific locations identified in this analysis is included in the geospatial dataset presented during the training presented in the July 2018 workshop for this project in Lilongwe.**
- **The validation of individual projects that ESCOM (or off-grid project developers) may be considering will likely require additional, intensive, face-to-face GIS training with project planners and engineers, most likely at ESCOM and MAREP.**
- **The results of this analysis are general and "first-order", rather than algorithmically optimized, with "sequenced" grid roll-out.**

2 Introduction

This report presents analytical results and conclusions for electrification planning for the project First Order Geospatial Least Cost Electrification Plan for Malawi. The objectives of a "first order" geospatial plan are:

- To identify near-term targets for grid access and validate proposed electricity access programs underway and due for expansion, including intensification in range of exiting grid, and extension to areas nearby;
- To identify a limited number of high-impact locations for off-grid systems (mini-grids) for areas that are not within range of grid extension in the near term (5-10 years).

Results and planning recommendations related to each of these objectives are presented in summary form in the following section (Section 3). More complete tabular results and maps, with details for smaller administrative units – including Malawi's districts, Traditional Authorities (TA) and Sub-chiefs (SC) – are contained in the Annexes at the end of the document. Other issues, such as data sources and analytical methodologies, have been addressed in detail in prior documents for this project (such as the Interim Report) and are reviewed in brief in later sections of the document (Sections 4 and 5). These include data obtained for the analysis, preparatory steps required to enable geospatial analysis, and examples of analytical outputs and related strategic insights.

The work for this project was directed by Edwin Adkins, Project Manager and Geospatial Electrification Planning Specialist, Millennium Promise Alliance (USA, NYC), with important contributions from other members of the consortium, including: Vijay Modi, Columbia University and Millennium Promise (NYC); Markus Walsh and Wilbert Simbila with AFSIS (Tanzania); off-grid specialist Federico Hinrichs with ECA (UK). Funding for this project, and support during in-country missions, workshops, and meetings were provided by the World Bank based in Lilongwe and Washington, D.C.

3 Key analytical results and conclusions for electrification planning

This section addresses the four key analytical results and conclusions for electrification planning:

- **The overwhelming majority of Malawi's current and future population lives close to existing ESCOM MV grid lines**
- **Major access gains can be achieved by "intensification": connecting those in range of existing transformers**
- **A geospatial analysis prioritizing MV grid extension recommends a set of 109 "high" or "very high" priority locations with over 100,000 households.**
- **Capex for grid connections can be reduced at least 25 percent under best practices of a national electrification plan**
- **Off-grid electrification will, in the near term, focus on "pre-electrification" for sites that will likely wait several years for grid access**

Brief descriptions, examples and summary data are provided for each of these points in this section. More detailed discussion of the analytical processes that led to these conclusions is provided in Section 5, and more complete quantitative results, maps and other outputs are contained in the report's Annexes.

3.1 Most of Malawi's population lives close to existing ESCOM MV lines

The most important strategic message emerging from this analysis is the very high percentage of the country's population that currently lives close to existing ESCOM electricity grid. Accessibility to the grid is visualized in Figure 1 which shows shaded areas 5 km (green) and 10 km (blue) from existing ESCOM medium voltage (MV) grid lines at two scales. The left panel illustrates the national area of Malawi, highlighting how an overwhelming proportion of the nation's surface is covered by these 5 and 10 km grid "buffer" distances. The few large areas that are not clearly within close range of the grid are the open spaces of Nkotakhota Wildlife preserve and Kasungu, Nyika, Liwonde and Najete national parks. The right panel provides a closer view of an area near Lilongwe which emphasizes this point further: the majority of this scene is shaded green, indicating a grid distance of less than 5 km, or blue (10 km grid distance), while only small "slivers" of areas fall in the unshaded area beyond the 10 km grid radius. This creates unusually good conditions in Malawi compared with many other countries in sub-Saharan Africa to achieve rapid gains in grid access at relatively low cost.

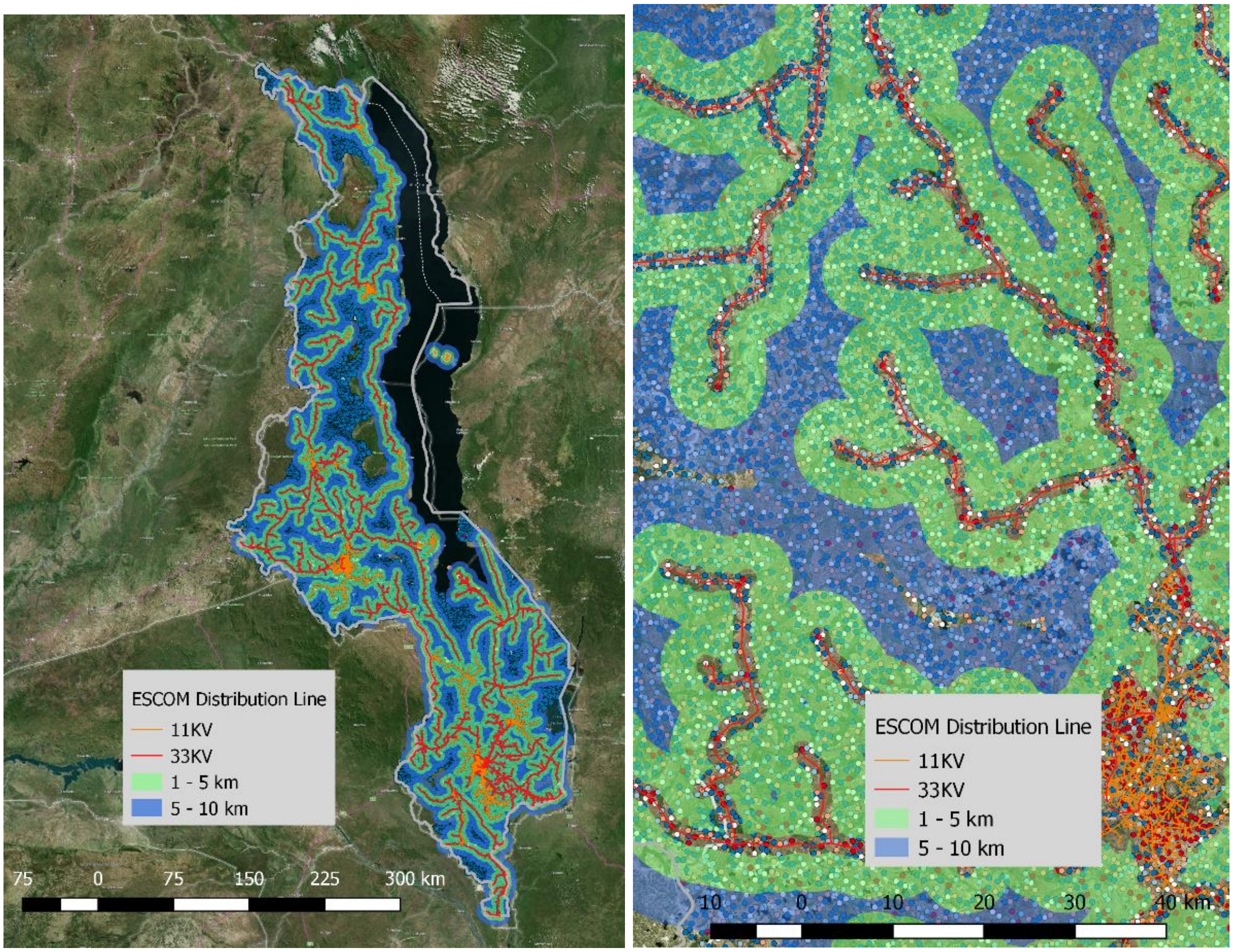

Figure 1: National scale (left) and an area near Lilongwe (right), showing areas 5 km (green) and 10 km (blue) from existing ESCOM MV lines.

This same conclusion is supported quantitatively by **Error! Reference source not found.**, which presents results for population projections from 2018 – 2030. These projections are based on geospatial population data derived from the High Resolution Settlement Layer (HRSL)[1] combined with district-level growth rates presented in Malawi's national census data.[2] The cumulative population values for all years, highlighted in red, show that an estimated 82-83% of

[1] High Resolution Settlement Layer (https://www.ciesin.columbia.edu/data/hrsl/)

[2] Malawi 2008 Population and Housing Census, Main Report and Population Projections, Malawi National Statistical Office (http://www.nsomalawi.mw)

Malawi's current and future population reside within 5 km of existing ESCOM lines. If this distance is extended to 10 km, the population percentage rises to more than 95%.

Table 1: Percentage of national population various distances from existing grid lines, with population growth to 2030.

Population totals and percentages, Natiowide									
		2018		2020		2025		2030	
Distance to existing MV lines (km)	All Regions	18,754,618	Cumul.	19,934,753	Cumul.	23,203,091	Cumul.	26,941,610	Cumul.
	1	8,307,410	44%	8,884,699	45%	10,485,104	45%	12,320,341	46%
	2.5	3,620,618	64%	3,821,947	64%	4,379,121	64%	5,011,928	64%
	5	3,528,970	82%	3,732,130	82%	4,294,372	83%	4,936,043	83%
	10	2,607,002	96%	2,762,357	96%	3,192,190	96%	3,684,893	96%
	15	510,460	99%	542,260	99%	630,215	99%	731,303	99%
	20	133,873	100%	142,374	100%	165,806	100%	192,644	100%
	25	35,429	100%	37,553	100%	43,318	100%	49,808	100%
	>25	10,857	100%	11,431	100%	12,966	100%	14,651	100%

Detailed data presented in Annexes A and B shows that this pattern is borne out throughout the country. Virtually the entire country, even the most rural districts, have between 70% and 90% of the population within 5 km. In other urban districts (Blantyre / Blantyre City, Lilongwe City, Mzuzu City) or higher density districts nearer to urban centers or the lake (Chiradzulu, Karonga) the percentage is even higher, with 99-100% of the population residing within 5 km of the grid (see Annex B).

The implication for electricity access planning, implementation and sector investment financing is that grid is likely to be the dominant least-cost electrification technology for Malawi. At the level of technical planning for ESCOM and MAREP, a comprehensive national least cost grid rollout plan, with a systematically staged implementation program, will address the near-term implementation (2019-2022) of intensification in areas close to existing LV network with extensions and connections in more distant rural areas of Malawi.

3.2 Major access gains can be achieved by "intensification": connecting those in range of existing transformers

The most important practical insight for electrification planning for Malawi in the very near term (2019-2022) is the large number of potential connections in range of existing transformers who can be reached with little to no additional medium voltage line. The lowest cost connections to make in the short term would be those within 1 km of existing ESCOM lines, that is 40-45% of the national population or around 1.5 million households. Since only around 300,000 are already connected, this leaves a large potential number of connections very close to existing lines. While cost predictions for are uncertain given the lack of information for grid costs in Malawi for large-scale roll-out, a rough estimate of US$450-500 per connection has been assumed based on national grid expansion programs in other countries.

Table 2 below shows results of a geospatial comparison of existing ESCOM account locations compared to the total number of estimated households within 500 meters and 1 km of existing ESCOM transformers and compared with all households nationwide.

Table 2: Existing and potential connections with 500 m and 1 km of existing ESCOM transformers.

Region	Distance from Existing Transformers	Total number of households	Existing ESCOM Account	Current Coverage, as a Percent of Households within 1 km Nationwide	Current Coverage, as a Percent of All Households Natiowide	Potential Coverage, as Percent of All Households Nationwide
National Total	**0 - 1 km**	**1,501,846**	**294,518**	**20%**	**7%**	**38%**
	< 500 m	1,096,115	294,518	**27%**	**7%**	**28%**
	500 m - 1 km	405,731	0	**0%**	**0%**	**10%**
Central	**0 - 1 km**	**588,565**	**93,914**	**16%**	**5%**	**34%**
	< 500 m	452,532	93,914	**21%**	**5%**	**26%**
	500 m - 1 km	136,034	0	**0%**	**0%**	**8%**
Northern	**0 - 1 km**	**160,954**	**49,170**	**31%**	**11%**	**35%**
	< 500 m	109,725	49,170	**45%**	**11%**	**24%**
	500 m - 1 km	51,229	0	**0%**	**0%**	**11%**
Southern	**0 - 1 km**	**752,327**	**151,434**	**20%**	**9%**	**43%**
	< 500 m	533,858	151,434	**28%**	**9%**	**30%**
	500 m - 1 km	218,469	0	**0%**	**0%**	**12%**

The existing number of about 300,000 ESCOM meters is only 20% of the 1.5 million homes within 1 kilometer and only 7% of all households at any distance nationwide. It is estimated that connecting the remaining ~800,000 homes within 500 m would bring the total from the current 300,000 ESCOM accounts to ~1.1 million, achieving an access rate of 28% nationwide. By contrast, connecting the remaining ~400,000 households slightly further away -- between 500 and 1,000 m – would add another 10%, bringing the national access rate to 38%.

While it complicates the description somewhat, the point of including household totals for both the 500 m and 1 km distances is to illustrate that the number of customers who could be reached with an intensification program depends upon the maximum low voltage length ESCOM is willing to extend. Current ESCOM practice limits LV lines to 500 m, which is low by international standards. Many utilities allow extensions up to 1 km or beyond. Increasing ESCOM's limit from 500 m to 1 km could "open up" an additional estimated 10% of the national population to low cost, LV-only grid extension. Having made this point here, other sections of this document use ESCOM's limit of 500 m surrounding transformers as the maximum distance for LV lines.

In any case, an intensification program focused mostly on LV extensions would allow ESCOM to triple or quadruple the total number of connections in a short timeframe at relatively low cost. The table indicates that the potential gains are greatest in the Central Region, where grid penetration currently reaches only 16% of the potential connections, and an estimated 500,000 more connections could be added within 1 km. Table 3 provides data for potential connections through intensification by district, using the more restrictive limit of 500 m for LV lines. This table shows that urbanized districts offer the greatest opportunity for these low-cost connections. Lilongwe, Mzimba, Blantyre, and Zomba, with a total of more than 175,000 potential connections in 2018 account for more than half of the total potential intensification connections nationwide.

Table 3: Potential number of connections by intensification for each district

Intensification Potential with Household estimate, by District						
Region	Locations	ESCOM Accounts	Unconnected Households (estimate)			
District		2018	2018	2020	2025	2030
National Total	**4,639**	**294,518**	**801,597**	**885,809**	**1,119,373**	**1,388,139**
Central	**1,605**	**93,914**	**358,618**	**398,801**	**510,570**	**640,161**
Dedza	112	2,483	16,776	17,682	20,170	22,955
Dowa	135	5,184	16,295	18,081	22,943	28,543
Kasungu	221	7,447	24,080	26,551	33,533	41,839
Lilongwe	622	56,662	232,563	261,849	343,422	437,969
Mchinji	96	4,549	18,368	20,010	24,605	30,027
Nkhotakota	101	5,232	12,539	13,681	16,882	20,571
Ntcheu	137	5,279	13,935	14,965	17,741	20,886
Ntchisi	49	2,361	4,927	5,418	6,784	8,405
Salima	132	4,717	19,135	20,563	24,490	28,968
Northern	**757**	**49,170**	**60,555**	**69,656**	**94,709**	**123,563**
Chitipa	61	3,613	2,245	2,554	3,359	4,228
Karonga	139	7,744	9,845	10,950	13,995	17,445
Likoma	22	0	2,258	2,264	2,280	2,285
Mzimba	319	29,595	33,718	40,181	58,149	79,175
Nkhata Bay	111	2,778	6,919	7,554	9,261	11,133
Rumphi	105	5,440	5,571	6,152	7,665	9,298
Southern	**2,277**	**151,434**	**382,424**	**417,352**	**514,094**	**624,415**
Balaka	127	5,312	12,909	14,118	17,529	21,483
Blantyre	468	76,309	153,038	170,204	216,985	270,074
Chikwawa	143	6,753	20,565	22,226	26,858	32,151
Chiradzulu	129	3,068	11,560	11,959	13,008	14,070
Machinga	115	5,177	14,269	15,528	19,135	23,364
Mangochi	257	10,901	51,284	55,816	68,845	84,243
Mulanje	175	6,888	19,871	20,603	22,597	24,688
Mwanza	44	3,186	5,201	5,450	6,054	6,622
Neno	48	2,059	2,306	2,713	3,833	5,081
Nsanje	108	4,121	16,894	17,982	21,053	24,651
Phalombe	67	2,709	8,969	9,603	11,441	13,540
Thyolo	308	9,244	25,726	27,025	30,666	34,609
Zomba	288	15,707	39,830	44,125	56,092	69,837

3.3 A geospatial analysis prioritizing MV grid extension recommends a set of 109 “high” or “very high” priority locations with over 100,000 households.

Looking beyond the 500 m range that can be electrified by LV “intensification”, potential extensions of medium voltage grid line can also be prioritized by a geospatial analysis.

- **Medium term grid access is likely to focus on areas beyond the 1 km range but within 5 km,** which represents an additional ~35% of population, or, when added to all households within 1 km, becomes ~80% of the population cumulatively. Costs for this geographic range have been estimated to be ~$750-950 per connection, on average.
- **The longer term would target higher cost households at greater distance, those 5 - 15 km from existing ESCOM lines.** This represents ~15% of the population, or another ~ 250,000 – 300,000 connections, and would bring grid access to nearly every populated place in Malawi. Costs are even more approximate for this portion of the extension program, since households and communities become more remote and more widely separated, so an estimate of ~US$950-1,250 per connection.
- **Finally, there are households that are furthest from the grid, more than 15 km, which could be considered for grid access over the long term, or as possible candidates for off-grid service, or both.** This is a small portion of the population, expected to be less than 1%. It is very difficult to predict grid connection costs for this category, so an estimate of US$ 1,500 – 2,000 per grid connection should be considered a rough guess based on international experience. Crucially, these locations may be more cost-effectively served by off-grid systems, either in the short-term, as a “pre-electrification” step, or the long term.

Using these unit cost estimates per household, the total costs for grid electrification program is estimated in Table 4 below. While this table includes a lot of information, focusing only on the information highlighted in red font, the total annual costs to achieve full grid access for all households within 5 km of existing grid lines is estimated to be around US$255 M annually between 2018 and 2030. The more limited goal of connecting only those within 1 km of existing ESCOM lines is estimated to cost around US$95 M per year over the same period.

Table 4: Total costs for grid electrification using connection cost assumptions based on distance from existing ESCOM lines.

	2018	2018-2030	2030						
	Total Households to be connected	New HHs from Pop Growth	Total Households to be connected	Percent of Total Conn-ections	Cost Per Connection	Total cost	Percent of Total Invest-ment	Annual Investment (12 years, assuming 100% grid access)	Cumulative Annual Investment
National	**3,944,781**	**1,846,403**	**5,791,184**		**$715**	**$4,140,013,646**		**$345,001,137**	
1	1,589,974	906,347	2,496,321	**43%**	$460	$1,148,307,451	**28%**	$95,692,288	**$95,692,288**
2.5	822,249	314,883	1,137,132	**63%**	$756	$859,671,502	**49%**	$71,639,292	**$167,331,579**
5	797,427	317,529	1,114,956	**82%**	$947	$1,055,863,461	**74%**	$87,988,622	**$255,320,201**
10	583,013	241,543	824,556	96%	$947	$780,854,932	93%	$65,071,244	$320,391,446
15	112,898	49,165	162,062	99%	$1,250	$202,577,804	98%	$16,881,484	$337,272,929
20	29,301	12,998	42,299	100%	$1,500	$63,448,400	99%	$5,287,367	$342,560,296
25	7,588	3,122	10,710	100%	$2,000	$21,420,015	100%	$1,785,001	$344,345,297
>25	2,331	817	3,148	100%	$2,500	$7,870,080	100%	$655,840	$345,001,137

To set aside the large, national estimates and reduce the number of locations to consider in the short term, this analysis has established four priority categories for possible MV extensions, with associated selection criteria. These are summarized in Table 5 below. (Although intensification requires only minimal little MV extension, it is listed in this section along with the MV extension options for comparison).

Table 5: Priority categories for MV line extensions (LV "intensification" is included for reference / comparison)

Priority	Distance from grid	Population of Settlement
Intensification (highest)	< 500 m	Any
Very High	< 5 km	1,000 and above
High	< 5 km	500 – 1,000
Moderate	< 5 km	250 – 500
Low	< 5 km & < 250 population | or | any size community > 5 km	

The results of the geospatial analysis which reviewed all settlements throughout Malawi with respect to these criteria is presented in Table 6 below. Because the purpose of this GIS analysis is to identify electrification targets and projects for the near term, the two categories that receive the most attention in this section are the "high" and "very high" priority categories, which are those settlement that are, first, within 5 km of existing grid lines, and have population of 500 – 1,000 (for "high" priority) and more than 1,000 (for "very high" priority). Results for these two categories are highlighted in yellow ("high" priority) and red ("very high" priority) in the table.

Table 6: Potential MV grid extension projects, with emphasis on "high" or "very high" priority locations as defined by distance and settlement size.

Priority Project Locations with Household estimate, by Region						
Area	**Locations**	**ESCOM Accounts 2018**	**HHs (est.) 2018**	**HHs (est.) 2020**	**HHs (est.) 2025**	**HHs (est.) 2030**
National Total	**88,490**		**3,944,781**	**4,210,791**	**4,947,915**	**5,791,184**
High + Very High	**109**		**111,009**	**119,484**	**143,216**	**170,753**
Intensification	4,639	294,518	801,597	885,809	1,119,373	1,388,139
Very High	22		55,115	59,844	73,075	88,439
High	87		55,894	59,640	70,142	82,314
Moderate	1,073		344,169	363,863	418,772	481,720
Low	82,669		2,688,007	2,841,635	3,266,554	3,750,572
Central	**33,147**		**1,726,283**	**1,853,031**	**2,204,784**	**2,612,605**
Intensification	1,627	93,914	360,876	401,065	512,850	642,446
Very High	9		17,871	19,801	25,171	31,391
High	36		22,453	23,884	27,838	32,390
Moderate	519		165,063	175,122	202,912	234,931
Low	30,956		1,160,019	1,233,159	1,436,013	1,671,447
Northern	**22,634**		**462,367**	**494,638**	**581,115**	**677,308**
Intensification	735	49,170	58,297	67,392	92,429	121,278
Very High	5		8,427	9,133	11,074	13,311
High	5		2,767	2,958	3,475	4,060
Moderate	21		6,552	6,989	8,189	9,547
Low	21,868		386,323	408,166	465,948	529,111
Southern	**32,709**		**1,756,132**	**1,863,123**	**2,162,015**	**2,501,271**
Intensification	2,277	151,434	382,424	417,352	514,094	624,415
Very High	8		28,817	30,911	36,830	43,737
High	46		30,674	32,798	38,828	45,865
Moderate	533		172,553	181,751	207,671	237,242
Low	29,845		1,141,665	1,200,310	1,364,593	1,550,013

These results show – yellow and red rows – that this GIS analysis identified 109 population clusters nationwide, including an estimate 111,000 potential household connections, that are within 5 km of existing grid and have either 500 – 1,000 people ("high" priority) or more than 1,000 ("very high" priority). Most of these communities lie within the 1 km range of grid, and so could be considered "intensification" depending upon the definition (500 m or 1 km). Nearly half of these communities (54) are in the Southern Region, accounting for an estimated nearly 60,000 potential household connections. Somewhat less than half (45) are in the Central Region, for around 40,000 potential household connections. Relatively few communities (10) are in the Northern Region accounting for an estimated 11,000 potential connections. A more detailed list showing the location of these projects down to the level of the TA or SC is presented in Annex C at the end of this report.

3.4 Capex for grid connections can be reduced at least 25 percent under best practices of a national electrification plan

Table 7 below shows estimates of costs per connection for urban, peri-urban and rural areas under two different connection scenarios. The first scenario presents costs that ESCOM currently uses in commercial planning for limited scale and low penetration connection projects undertaken mostly as part of incremental, annual plans. The second scenario presents reduced costs that can be expected through implementation of a national electrification plan with "high scale and penetration", bulk procurement, international competitive bidding, economies of scale in grid planning, design and construction, and other features of a large-scale, national roll-out. (The rationale for anticipated cost reductions is presented in detail in section 4.3 of this report)

Table 7: Capex per grid connection can be lowered substantially – 25 percent at least – under a national electrification program scenario with high scale and penetration

	Best guess estimate	Capex estimate Business as usual (ESCOM Commercial) Low Scale and Penetration - Projects scenario						Capex estimate National Electrification Program (Malawi NEP) High Scale and Penetration - Program Scenario*					
Notes		**M**	**Urban**	**m**	**Peri-Urban**	**M**	**Rural**	**m**	**Urban**	**m**	**Peri-Urban**	**m**	**Rural**
MV/KM (33 kV)	$13,000	10	$143	13	$390	43	$520	10	$143	13	$390	20	$520
LV (3ph)	$10,000	32	$320	33	$330	57	$570	20	$200	20	$200	25	$250
Connection (Avg)	$150		$150		$150		$150		$150		$150		$150
Extra Pole	$81				$16		$27				$16		$27
Total			**$580**		**$886**		**$1,267**		**$460**		**$756**		**$947**
ESCOM Reference			$559		$612.00		$1,327						
ESCOM Connection Type / Description		Urban "High Density"		Urban "Medium Density"		Urban "Low Density"							

*** Indicative estimates informed by international electrification program experiences with good practices for cost-saving relevant to Malawi context.**

These estimates are sensitive to both unit costs – including cost per km for grid lines and connection costs related to meters, service drops and other equipment – as well as geographic distances – such as distances between communities (which determine medium voltage line lengths) and distances between households (which determine LV line needs per connection). The most important insight is that the national electrification program scenario (shown at right in the table, with cost estimates based on high-penetration) offers potential to reduce capital costs per

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new grid connection by around 25 percent or more, over the long run, as expenses for the grid "backbone" are spread among many more connections.

3.5 Off-grid electrification will, in the near term, focus on "pre-electrification" for sites that will likely wait several years for grid access

Another key strategic implication of this analysis is that an appropriate and coordinated combination of off-grid implementation modalities – individual home solar products and isolated small network systems – can potentially play major role in pre-electrification in the interim while a program of least-cost, staged grid extensions progressively reach settlements that may wait for five years or more for grid connectivity.

Geospatial screening to select mini-grid target sites

An important component in this geospatial work has been to perform rapid geospatial screening to select candidate sites. The first round of screening used two criteria: settlements should be at least 10 km from the existing ESCOM MV grid lines, and each location has an estimated population of more than 750 persons, or about 250 homes. These criteria, taken together, help ensure that the selected locations are sufficiently far from existing lines that they are unlikely to be connected to grid within 5 years and that they contain sufficient population and electricity demand to justify the effort to electrify.

Figure 2 below provides an example from a lakeside area in Lilongwe District (Central Region) illustrating the first stage of this geospatial screening approach. The upper panel shows the broader area, for context, while the lower panel shows a closer view of the candidate locations. Candidate settlements far from the grid are shown with population values in blue font. Straight line distances from the grid are shown as yellow dashed lines with km distances in black font. The distances of some communities from the grid are large, in this case 10-12 km, as can be seen from the fact that they lay outside the blue 10 km buffer zone. For other candidate sites, the distances exceed 25 km. Also, the populations that can be reached with off-grid technologies are substantial – in this example, both communities are estimated to have more than 1,300 inhabitants.

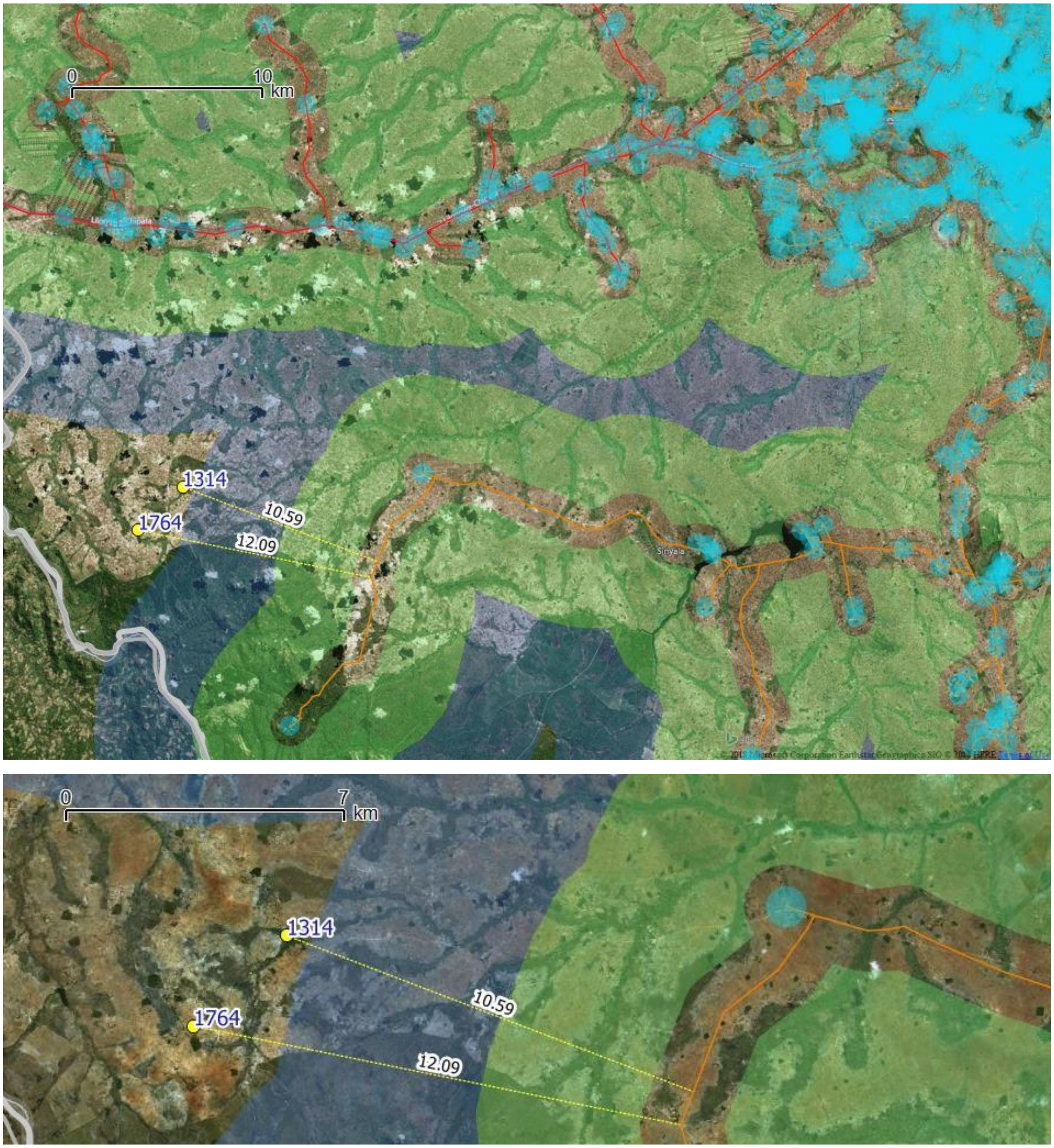

Figure 2: Candidate locations for off-grid systems (>10 km from grid, population > than 750)

Application of these same criteria throughout Malawi led to selection of 74 locations as candidate target sites for off-grid "pre-electrification". The full list of candidate locations is presented in Annex D. Summary results of this screening are presented in Table 8 below.

Table 8: Summary of the 74 off-grid "pre-electrification" candidate locations selected by the first round of screening for off-grid sites

Off-Grid Candidate Sites with Household est., by Region				
Region	**Sites**	**Ave. Distance to Grid**	**Population (est.)**	**Households (est.)**
District		**km**	**2018**	**2018**
National	**74**	**14**	**81,639**	**18,508**
Central	**39**	**12.5**	**39,804**	**8,865**
Dedza	10	12.5	8,734	1,945
Dowa	2	11.1	2,100	468
Kasungu	1	13.6	1,109	247
Lilongwe	11	11.0	12,447	2,772
Mchinji	8	14.1	8,846	1,970
Nkhotakota	1	19.6	790	176
Ntcheu	2	12.3	2,347	523
Ntchisi	1	12.3	811	181
Salima	3	12.5	2,619	583
Northern	**8**	**15.8**	**7,542**	**1,536**
Mzimba	7	16.1	6,790	1,383
Rumphi	1	13.3	752	153
Southern	**27**	**14.5**	**34,293**	**8,106**
Chikwawa	6	13.6	5,295	1,252
Machinga	4	11.7	4,772	1,128
Mangochi	17	15.5	24,226	5,726

The majority of selected sites are in the Central and Southern Region: 66 locations (39 and 27 respectively) with a total of estimate of nearly 17,000 households. By comparison, relatively few candidate sites and households were found in the Northern Region. The total number of candidate sites presented here is 8-10 times the number of locations called for in the terms of reference (ToR). The extra sites are provided here for a few key reasons. Various issues may complicate site selection and require consideration of alternate sites. These issues include inaccuracies in population estimates derived from satellite imagery, limited accessibility for some sites, or additional local electricity demands such as markets that are not accounted for in our data.

Candidate sites tend to fall into clusters. Because there are few areas of Malawi more than 10 km from the grid, those few unserved areas tend to have multiple settlements many of which are favorable locations. For example, as can be seen in Table 8, the first round of screening identified 17 candidate locations in Mangochi District, more than any other district. Ten of these villages fall in an area on the lake coast more than 15 km from the nearest grid line and transformers. This cluster of candidate sites, and other smaller clusters throughout the country, may suggests an implementation pattern in which off-gird technologies are tested in one village, and, if successful, scaled-up to neighboring communities.

Figure 3: A "cluster" of ten candidate sites identified in the first round of screening for off-grid sites (Mangochi District)

While this longer list of 74 "pre-electrification" candidate sites may be useful, the project's terms of reference (ToR) nonetheless calls for a more limited number for consideration in the short term, so additional criteria were added to refine this list. Typically, one of the highest priority goals of electricity access programs is power for health needs, particularly in rural clinics that serve isolated communities. To address this goal, the 74 sites identified previously were screened a second time to identify a sub-set of locations within 1 kilometer of a health facility requiring electric power. There are many types of health facilities serving rural areas with a range of offered services. In consultation with local development practitioners in Malawi, we determined that the facility types most likely to require electric power in Malawi are health centres and dispensaries.[3] This second screen refined the selection to eight sites which are shown in Figure 4, with the number showing the number of households for each.

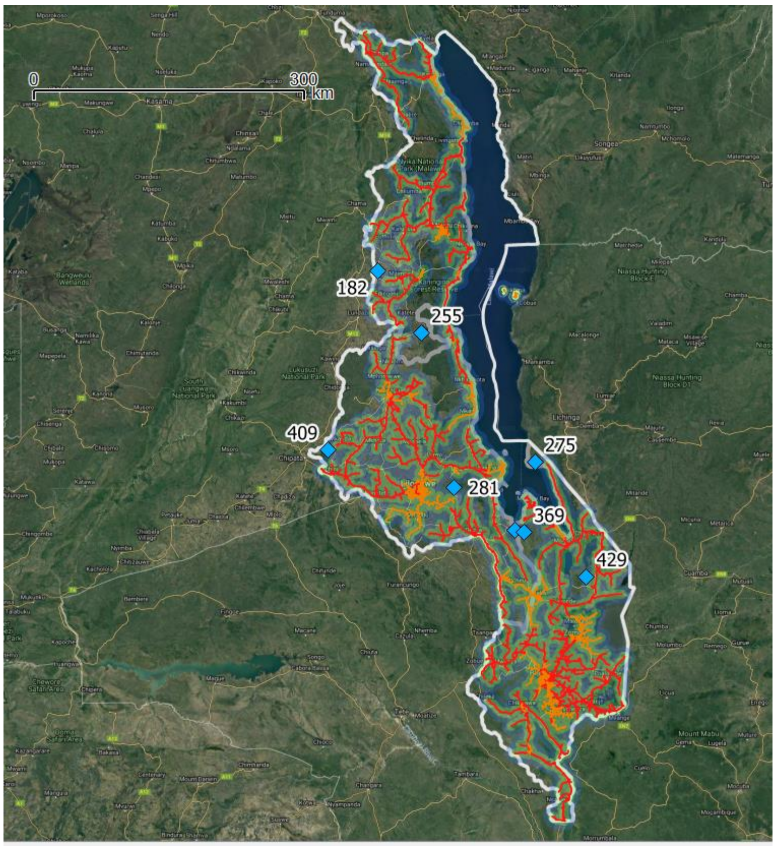

Figure 4: Eight priority sites for off-grid project implementation (with household number).

Further details for this shorter list of sites are listed in Table 9 below, including the geo-coordinates, distance from the nearest ESCOM grid line, information on the location's administrative areas, population and distance to nearest health facility.

[3] An electricity needs assessment initiated in early 2018 for Malawi is still underway. Health centres and dispensaries were confirmed by participants in this needs assessment from the UNDP as priority facility types for power access.

Table 9: Eight off-grid "pre-electrification" candidate sites that met all three screening criteria: > 10 km from grid, > 750 population and < 1 km of a health facility requiring power.

	x	y	Dist. to Grid Line (km)	Traditional Authority / Sub-Chief Name	District	Region	2018 HH Est.	Dist. to Health Facility (m)	Nearby Health Facility Name & Type
1	32.864180	-13.571450	10.7	TA Mkanda	Mchinji	Central	409	441	KAZYOZYO Dispensary
2	34.721170	-14.340200	14.1	TA Masasa	Ntcheu	Central	209	537	PHANGA Dispensary
3	34.124080	-13.933440	11.7	SC Chitekwele	Lilongwe	Central	281	324	CHIMBALANGA Health Centre
4	33.794080	-12.437330	17.0	SC Khosolo Gwaza Jere	Mzimba	Northern	255	433	KHOSOLO Health Centre
5	33.358620	-11.831770	14.8	TA M'Mbelwa	Mzimba	Northern	182	531	KAMTETEKA Health Centre
6	34.816400	-14.366170	12.5	Monkey Bay Urban	Mangochi	Southern	369	786	NANKUMBA Health Centre
7	34.925010	-13.688530	13.2	TA Makanjila	Mangochi	Southern	275	844	LULANGA Health Centre
8	35.437010	-14.793640	10.5	TA Liwonde	Machinga	Southern	429	256	MANGAMBA Health Centre

Detailed maps for the largest of these sites (number 8 on the list in Table 9 above) are presented in Figure 5 below as an example. The site is near the border of Mangochi and Machinga Districts, slightly more than 10 km from the existing ESCOM grid lines. The village contains an estimated 429 households, and as can be seen in the lower panel in Figure 5, it is near two health facilities: Mangamba Health Centre and Mtembo Village Clinic, both within 500 meters of the centroid identified for the village.

A list of all 74 sites selected in the first screening, with coordinates, settlement size, administrative areas, and other details is presented in Annex D. Following this table, the Annex also presents maps for the 8 sites that met the additional criteria of being within 1 km of an existing health centre or dispensary. Like the example presented in this section, these maps in Annex D also show both a wide view of the surrounding area for context, as well as a zoomed-in view which gives an indication of the overall area of the settlement, the degree of aggregation (or dis-aggregation) of households, and proximity to the health facility and other features, such as roads. Maps like these, against a satellite image background, help both to validate that the location meets the basic criteria for site selection (distance from grid and settlement size), but also help with the choice of technologies (home systems vs. mini- / micro-grids). An analysis like this can be modified to meet the goals of a pre-electrification program appropriate to Malawi's goals, budgetary constraints, and implementation timeline.

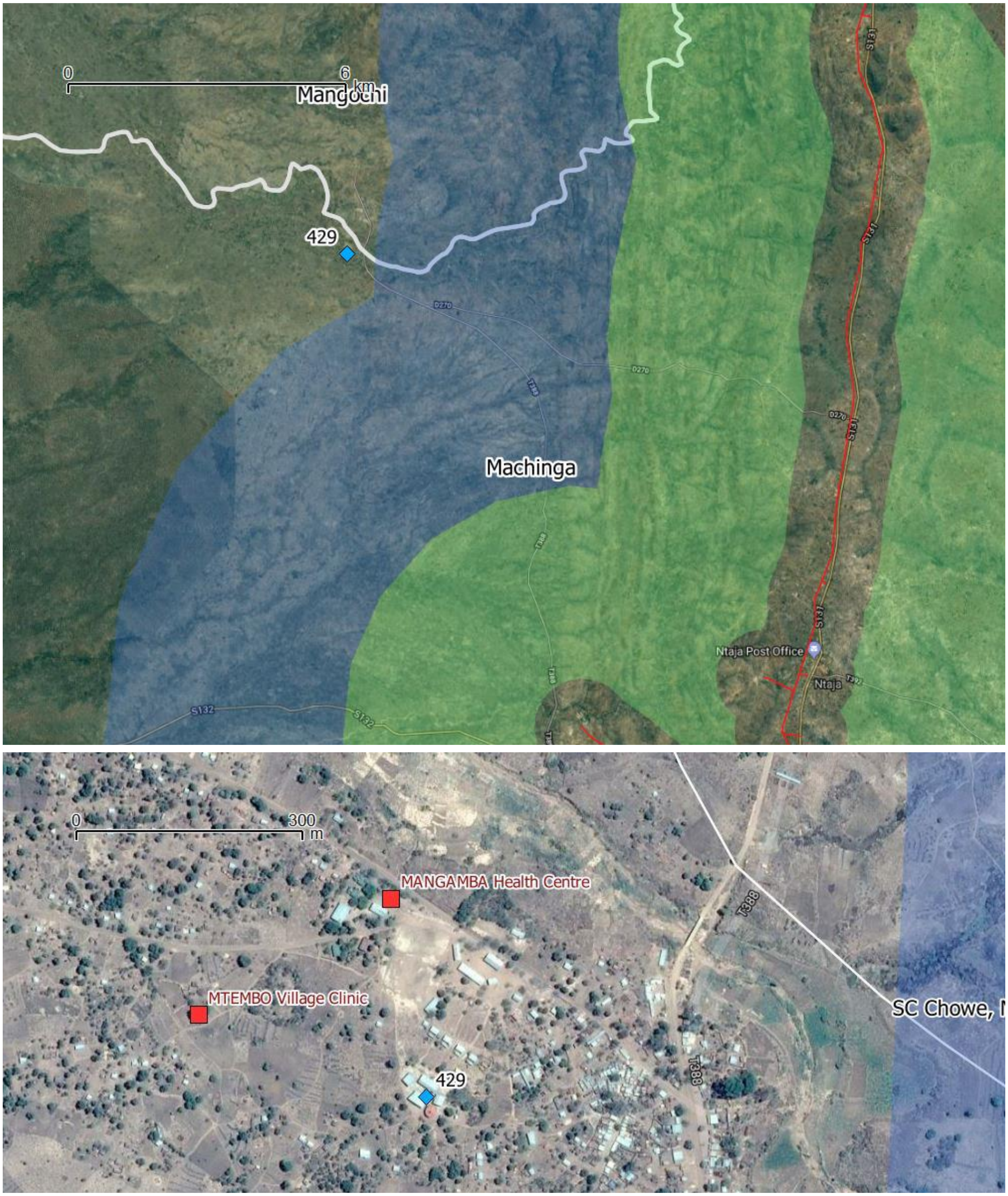

Figure 5: Wide view (top) and detailed view (bottom) of an off-grid "pre-electrification" candidate site identified in the second round of screening (429 households, TA Liwonde, Machinga District).

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Cost assessment and modeling for mini-grids

Another key aspect of the mini-grid investigation for this study has been an assessment of local costs for solar mini-grids, followed by modelling work to estimate the relative costs of mini-grids vs. other electrification option. This assessment and comparative modeling was performed by Federico Hinrichs of ECA using Excel workbooks that were provided, along with cost input data, to attendees to the July 2018 Lilongwe training. The purpose of this analysis has been to establish quantitative estimates for several parameters related to cost modelling for off-grid systems, including generation, storage, distribution, and management per system and per household, noting which values are based on information from within Malawi vs. other countries. This off-grid electrification analysis also provides a first-order assessment of the conditions (e.g. population density and energy consumption per household) that justify electrification via mini-grids versus competing technologies (grid expansion and stand-alone solar). The full report of this work can be found in Annex E of this document. This section provides a summary of information collected from three existing or proposed mini-grid sites (MEGA, Mchinji, and Nsanje), and interviews with those active in the sector, followed by costing analysis, including equipment, labour, transport, etc. Data collected was complemented with international benchmarks.

Technology costs: Solar PV systems (generation, storage, distribution)

- Average cost of off-grid solar PV in Malawi is $5,700/kWp (with storage, installed). This is 65% higher than a benchmark calculated based on mini-grids in East Africa (Kenya and Rwanda). However, according to solar PV installers, the cost in Malawi could be almost halved when using lower quality equipment.
- In the sites visited, battery storage was substantially larger in the Malawi mini-grids than in the benchmark. Comparing unit costs, Malawi solar PV costs ($/kWp) and battery costs ($/kWh) where between 40-50% higher than the benchmark.

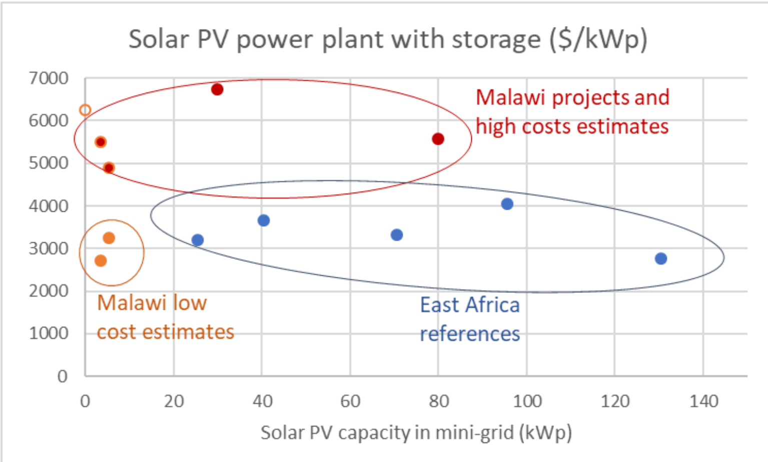

Figure 6: Costs for Solar PV power plant with storage ($/kWp) in Malawi and elsewhere

Characterisation of mini-grids

MERA is currently defining a mini-grids framework for Malawi which will include, among others, licensing procedures and technical standards to be followed. These aspects will have an impact on the cost of a mini-grid and thus on their competitiveness. For example, demanding that mini-grid networks follow technical standards similar to those of the national grid, may result too costly for rural areas with low energy demand. Countries with more advanced mini-grid frameworks (e.g. Tanzania, Rwanda, Kenya) have defined different types of mini-grids according to their size, location and level of service they provide. Different standards apply to the different types of mini-grids. We can anticipate that a similar approach will be adopted in Malawi. Therefore, for modelling purposes, will consider two broad types and sizes for mini-grids:

- **Type 1: Isolated mini-grids**. These typically under 50kWp of installed capacity, in isolated locations not planned for grid connection within 10 years. These mini-grids will provide basic access to electricity to most residential customers (Tier 1 and Tier 2) and make higher levels of access available for productive use. The distribution network (typically low voltage only) will be sized according to the needs of the site and will not follow the standards applicable to the national grid.
- **Type 2: Grid-standard mini-grids.** Better suited for larger villages/towns, with higher energy demand, offering a higher tier of electrification (between Tier 2 and Tier 3) and likely to be connected to the grid in the medium term (below 10 years). For this reason,

the design of the network will follow similar practices (and incur similar cost) as the national utility, in preparation for grid connection.

Cost Modelling

The costing of both types of mini-grids will be defined based on costs in Malawi and international benchmarks and will include both investment costs and operating costs.

- **Generation costs:** solar PV equipment, battery storage, power conditioning and BOS
- **Distribution costs:** wires and poles
- **Connection costs:** Line drop, circuit breaker, meter, etc.
- **Operating costs:** O&M, administrative costs, replacement of parts (e.g. batteries)
- **Other costs:** engineering, procurement, transport, installation, civil works, etc.

For competing technologies, we will assess cost of solar home systems and the cost of grid extension, including both CAPEX and OPEX.

Table 10: Costs for example mini-grids, Types 1 and 2

Cost component	Type 1 mini-grid	Type 2 mini-grid	Comments
Energy demand per HH (kWh/mo)	6 (Tier 2 lower threshold)	12 (higher end of Tier 2)	
Productive uses (maize mills, water pumping, etc.)	No	Yes	
Solar PV generator (incl structure and solar inverters) ($/kWp)	1,600		
Battery bank ($/kWh)	200		Storage sized at 1 day of autonomy at 50% DoD
Power conditioning and BOS ($/kWp)	800		
Total solar equipment ($/kWp)	***4,600***		
LV network ($/km) 3-phase backbone with single phase distribution to households	5,000	8,000	Cost of network serving low demand vs cost of grid-standards network
Single phase service drop ($/connection)	100	200	
O&M costs (% of capex p.a.)	1.5%		
Administrative costs ($/customer/a)	20		

Costs of two alternative technologies will also be compared to mini-grids:

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- Grid extension at a cost of MV network at $15,000 per km and transformer at $80/kVA
- Solar Home Systems (SHS) at $7-8 per Wp depending on size of system

The cost effective analysis (performed with excel models) determines **Levelized Cost Of Electricity (LCOE) of mini-grids versus solar home systems and grid extension**, given costs of each technology (per section above) and the following key variables:

- Energy consumption per customer
- Density of customers (meters of network required, per customer)
- Distance to the grid connection point

These factors are critical in determining what conditions have to be met for mini-grids (both for type 1 and type 2) to be viable versus competing technologies.

Preliminary conclusions of cost modelling

Type 1 mini-grids

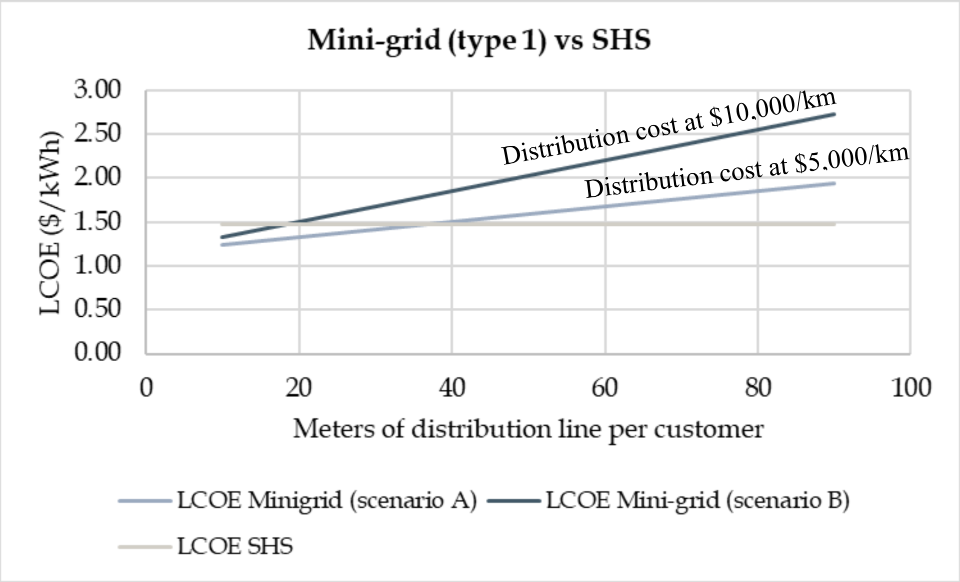
This model compares:

- 26kWp solar PV mini-grid serving 400 customers (90% of which are households consuming 6kWh/month) and also businesses and institutions with low energy consumption (e.g. hair dressers, general stores, cinema, etc.).
- The network is built below grid standard, commensurate with the low level of electricity demand.
- SHS for said 400 customers (50Wp units for households, 130 Wp for businesses and institutions), adding up to about the same total PV capacity as the mini-grid
- Cost of extending the MV network (33 or 11kV) to the site and supplying electricity at the grid cost

Results:

- Against SHS, the mini-grid has a lower cost (on a levelized basis) if the density of customers is such that the distribution network (excluding service drops) is no longer than 40 meters per customer (25 customers per km of distribution network). This is approximately equivalent to a density of 500-600 customers per square kilometre.

- Against extension of the grid, the mini-grid has a lower cost (on a levelized basis) if the MV network is further than 10 kilometres.



Type 2 mini-grids

This model compares:

- 100kWp solar PV mini-grid serving 600 customers (90% of which are households consuming 12kWh/month) and substantial energy demand from productive uses (40% of demand from businesses and institutions incl maize mills, water pumping, welding, refrigeration, etc.). The network is built to grid standard at a cost of $8000/km and $200 per connection.
- SHS for said 600 customers (100Wp units for households, 625 Wp for businesses and institutions), adding up to about the same total PV capacity as the mini-grid
- Cost of extending the MV network (33 or 11kV) to the site and supplying electricity at the grid cost

Results:

- Against SHS, the mini-grid has a lower cost (on a levelized basis) if the density of customers is such that the distribution network (excluding service drops) is no longer than 30 meters per customers (33 customers per km of distribution network). This is approximately equivalent to a density of 700-800 customers per square kilometre.

- Against extension of the MV grid, the mini-grid has a lower cost (on a levelized basis) if the MV network is further than 40 kilometres.

Overall conclusions

Solar PV mini-grids can, under certain circumstances, offer lower cost of electricity than solar home systems (SHS), diesel mini-grids or the extension of the grid to remote communities. Mini-grids are a cost-effective solution in general, when:

- Peak power and energy demands are expected to be moderate, under 100 kW and supplying less than 150 MWh a year per mini-grid. Sites with higher demands can be justified if ESCOM grid is not expected to serve that location within 5 years.
- There are many customers per community (e.g., 20 or more), so that there is sufficient electricity demand to justify setting up of the mini-grid infrastructure.
- Customers are in denser communities, (e.g., 500-800 customers/km^2 depending on the type of mini-grid, or more), so that distribution network costs are lessened. Sites like MEGA and Mchinji (Sitolo) are viable in this regard. Nsanje is not.
- Distance from the national grid is 10 to 40 km or more from the community to be served, depending on the energy demand of the site. The higher the energy demand, the more isolated it needs to be for solar PV and batteries to be viable against the national grid.
- There are productive/commercial loads, especially during daytime, permitting the mini-grid network and generation assets to be better utilized. Also, the willingness-and ability-to-pay of productive/commercial customers are higher than domestic customers thus increasing revenues.
- Adding a diesel generation as a back-up power source with solar PV mini-grids is justified as it could be lower cost than increasing capacity of solar PV and batteries to improve year-round electricity availability.

The following are possible steps to refine this cost effectiveness analysis:

- Improve (provide more details) the load profile and system sizing of mini-grids

- More scrutiny or additional information with regards to cost assessment
- Review energy demand assumptions based on NSO expenditure surveys and market assessments for solar lighting (BIF)
- Identify possible mini-grid sites in Malawi and provide rough estimates of energy demand, capacities and cost (perhaps in a later stage of geospatial analysis)

3.6 Concluding remarks and next steps

This section has thus far described the main insights gained from the geospatial analysis, focusing primarily on: a) the potential for rapid, low-cost electrification by low voltage "intensification" within 500 meters of existing transformers; b) medium voltage extensions to larger settlements within 5 km of existing grid (the "high" and "very high" priority settlements); and c) the identification of a short list of remote locations for prioritized development of off-grid services since they are unlikely to receive grid connections within the near future. While these results are helpful in themselves, particularly for broad insights into the relative cost-effectiveness of specific electrification strategies, there is more insight to be gained from this geospatial approach related to specific projects. Therefore, it is important to consider the practical implications related to using these results and associated datasets for more detailed recommendations and analysis, including possible next steps.

- **Greater detail for specific locations identified in this analysis is included in the geospatial dataset presented during the training in the July 2018 workshop in Lilongwe.** This training included not only a "handoff" of the data used in this analysis, but also an introduction to a free and open-source GIS software package (QGIS) that can be used to view the data as well as the spreadsheets used for prioritization of locations. All criteria used for prioritization are expressed in formulae written as expressions in Microsoft Excel, and so can be modified by local practitioners.
- **The validation of individual projects that ESCOM (or off-grid project developers) may be considering will likely require additional, intensive, face-to-face GIS training with project planners and engineers, most likely at ESCOM and MAREP.** ESCOM's list of proposed projects includes improvement / upgrading of existing lines,

addition of specific MV lines to serve individual communities or population corridors. MAREP has similar site assessments ongoing for rural electrification sites. Other local partners are seeking specific validation of potential off-grid sites. These sorts of localized, detailed analyses are amenable to many of the GIS datasets and analytical approaches used for this analysis, but that level of specificity was not possible in the national, "first order" analysis presented here. This kind of detailed approach can be taken, to for instance perform specific analyses or project reviews using GIS, but would require additional, face-to-face work with project planners and engineers This would include at least two steps that were not possible here: a) to undertake careful visual inspection of the local data from satellite imagery or other datasets on a project-by-project basis, and b) to validate GIS analytical conclusions with engineers who have practical, on-the-ground experience in target areas.

- **The results of this analysis are general and "first-order", rather than algorithmically optimized, with "sequenced" grid roll-out.** Due to the rapid, "first-order" nature of this project, the results presented here consider only community size and distance from the grid as key criteria for prioritization of line extensions. A more sophisticated analysis would perform an algorithmic, least-cost modeling effort to consider the sequential extension of the grid, prioritizing corridors of lower-cost grid connections, taking advantage of network effects. Both are achievable but require additional effort beyond the scope of this terms of reference.

4 Data Sources & Preparation

The "first order" geospatial analysis undertaken this project relies on three key data types as inputs:

a) Geolocated information for existing and future electricity demands, the most important being populated places and social infrastructure, with populated places represented by the High Resolution Settlement Layer (HRSL);
b) Geolocated information for existing electricity supply infrastructure, most crucially medium voltage lines and transformers for the national electricity grid, and geospatially specific information for electricity access throughout the country, provided by shapefiles for existing grid lines and equipment from ESCOM;
c) a range of additional parameters, the most important being: costs for various electricity technologies (provided by ESCOM and off-grid electricity project implementers), rates of change and growth (such as population growth rates from the national census).

The analysis may benefit from other data sources as well, including:

- Additional electricity demand information, particularly for social infrastructure facilities: the most important source of this type is likely to be a health sector demand underway as a collaboration between UNICEF and UNDP, though results were not be available in time for this project's completion.

These data resources have been discussed in more detail in prior documents, including the Interim Report for this project, and are here presented again briefly.

4.1 Geolocated Electricity Demands

High Resolution Settlement Layer (HRSL)

A critical data input for this analysis is the High Resolution Settlement Layer (HRSL), a geolocated population data product consisting of a grid in which each pixel has a population estimate derived from population data (at lower resolution) allocated to grid cells based on information or settlement patterns obtained from analysis of high-resolution satellite imagery. This data product was created as a collaboration between Facebook, which provided satellite image data and computing resources and machine learning, and the Center for International Earth Science Information Network (CIESIN) at Columbia University's Earth Institute, which provided expertise related to GIS, geolocated population data and demography. The HRSL presents something of a "big data" challenge, in that the data for Malawi has ~ 300 million pixels, ~ 100-150 million of which probably have some population. The challenge is to transform this grid data into communities or villages.

Due to the small cell size of ~30 meters, data cells are difficult to see when viewed at the national scale, but community locations and shapes become increasingly clear in the colored pixel clusters that are much more visible at the local scale (see Figure 7 below).

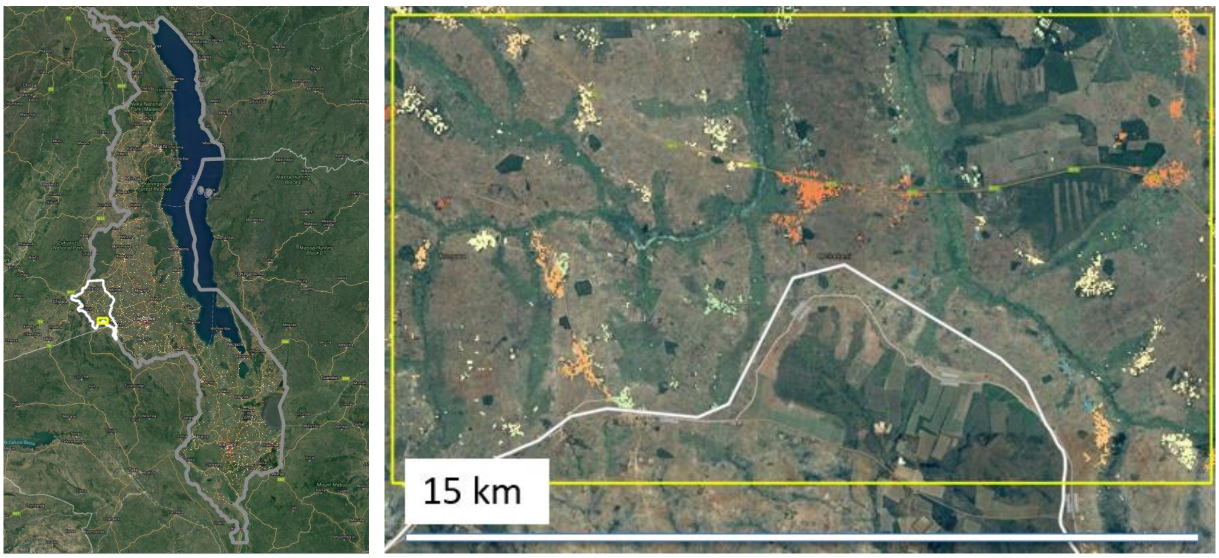


Figure 7: HRSL data at national scale (left) and local scale (Mchinji District, right)

The pixel clusters in these images show a single color for all pixels, indicating the same or similar population values assigned to neighboring pixels. This suggests that the processing that created the dataset assumed that population to be evenly distributed throughout a pixel cluster of a given size. Thus all population values for a single cluster can be aggregated and assigned to a single polygon with the boundary of the pixel cluster, and one centroid assigned to the cluster boundary. The second step in data preparation is to identify and combine centroids within 500 m of a nearest neighbor, summing the populations, to create potential transformers or locations for mini-grid centers. This process, with HRSL gridded data in the background, is summarized visually for a small local area in Figure 8.

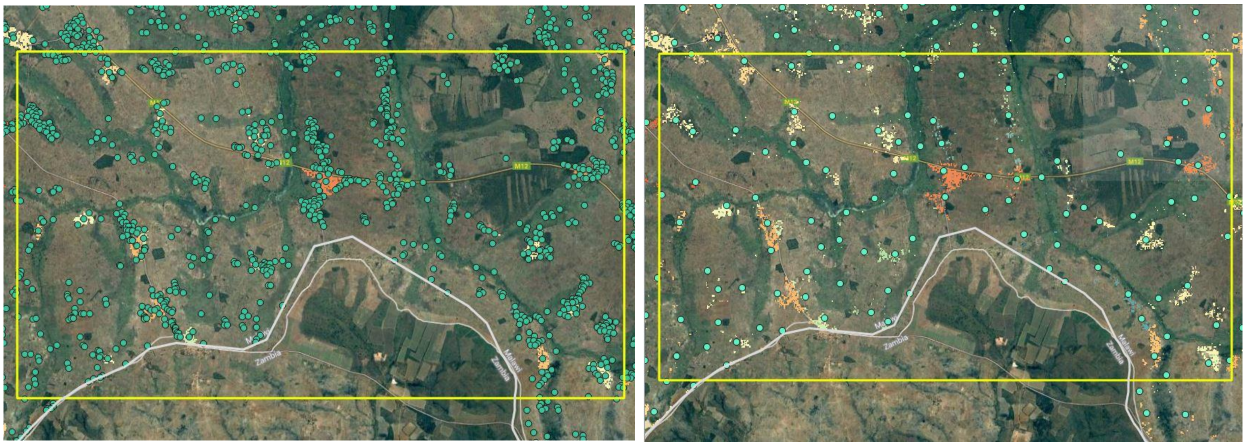


Figure 8: Identification of centroids within gridded polygons (left) followed by clustering of centroids to form potential transformer sites with 500 m coverage area (right).

The first step of creating centroids from the HRSL population areas simplifies the dataset without a significant loss of information, reducing the size of the dataset on the order of 1,000 times. This second step reduces it further, by approximately another factor of ten, by considering only locations for potential transformer sites. Further detail, at the level of low voltage line, is not appropriate for this project, but rather would be addressed in the design phase. The quantitative impact of these two steps on the data is shown in Table 11 below. For the Mchinji District, the HRSL provides from 1-3 million pixels, which reduce to ~25,000 centroids, and further to ~3,250 cluster centers – or potential transformer sites.

Table 11: Data processing to simplify and prepare the HRSL for electrification planning

	HRSL (Pixels)	HRSL (Centroids)	Clusters of Centroids
Malawi	~100 - 300 million	902,459	88,502
Northern Region		193,984	22,653
Central Region		279,131	33,153
Southern Region		429,344	32,696
Mchinji District	~ 1- 3 million	25,130	3,246
Test Area	~ 50 - 150,000	854	107
Reduction factor		~100 X	~10 X

Other Demands (Social infrastructure and trading centres)

As described in the Interim Report, there are several geolocated data sources relevant for electrification planning The main one employed for this analysis was the geolocated locations for 9,500 health facilities (see Figure 9 below) which were used to refine the selection of potential off-grid project sites.

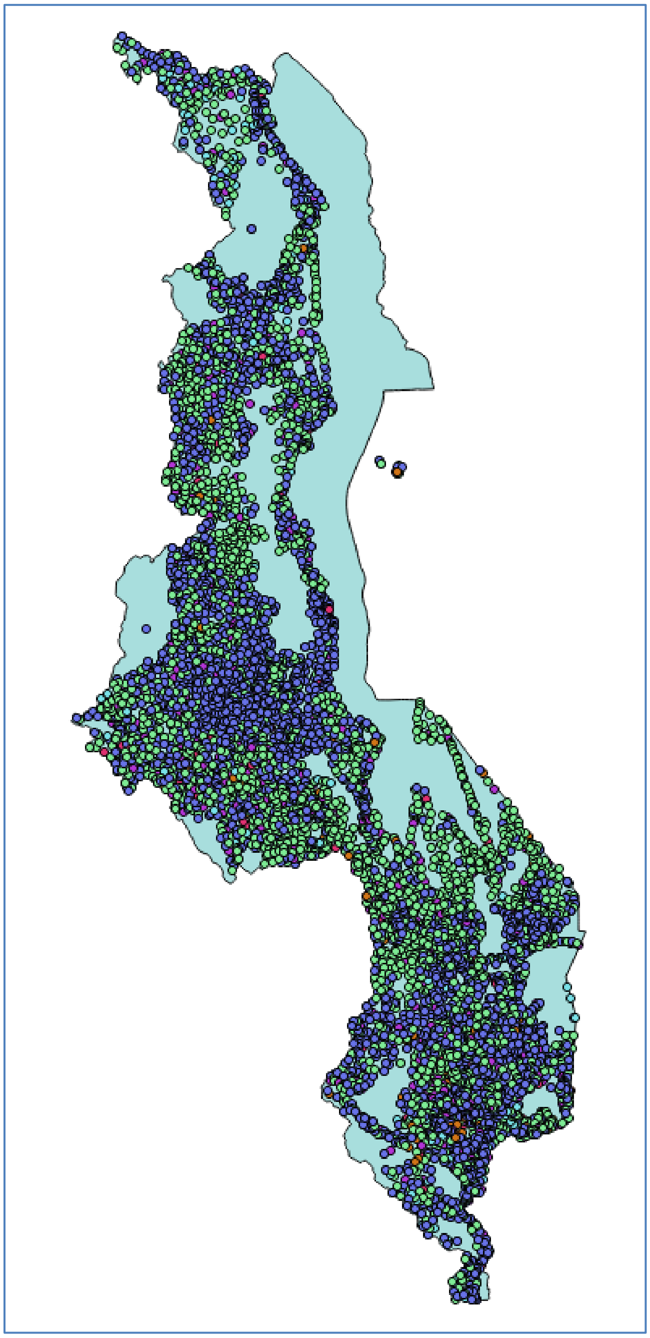


Figure 9: Geolocated data for social infrastructure: health facilities

There is also an effort recently initiated involving UNICEF and UNDP to assess electricity demands for health needs throughout the country at the level of individual facilities. The data from this assessment is expected to be a valuable input to future electrification planning, but this assessment was not complete in time for the "first order" plan specified in this project's terms of reference (ToR). The existing data for health facilities appears to be both detailed and includes helpful information distinguishing facilities by type (hospital, health centre, health post, dispensary, village clinic, and "outreach") which are expected to be helpful in predicting electricity demands by facility type. Data for locations of educational facilities exists, but lacks information for the schools' size or type, making it somewhat difficult to use for a demand analysis.

Grid expansion planning in rural areas – particularly through the Malawi Rural Electrification Program (MAREP) – is targeted toward "trading centres" which are generally understood to be concentrations of structures including shops and other non-residential buildings and are also likely to have health or education facilities nearby. The definition for these locations does not appear to have been formalized, and, more importantly, no nationally comprehensive map for trading centres is available. Data for on trading centres under consideration for electrification by MAREP is included in a later section of this document. Requests to MAREP during the Interim Mission to Malawi (early May) did not result in more trading centre data, but this may be available for later phases of Malawi's electrification planning.

4.2 Information for existing ESCOM grid infrastructure electricity supply

A nationally comprehensive and highly detailed map of existing grid infrastructure has recently been created for Malawi (see Figure 10 below). This dataset includes geolocated medium voltage (MV) grid lines, service transformers, and nearly 300,000 customer meter locations. The MV line data is in shapefile (line) format, includes 33 and 11 kV lines (~ 9,760 km total), with attributes of conductor size, feeder, substation, overhead / underground, and others. The data for service transformers is in shapefile (point) format, and includes ~5,730 points with attributes of capacity, weight, location, and others. The connection data is in point shapefile format, with attributes of feeder, customer account, and others.

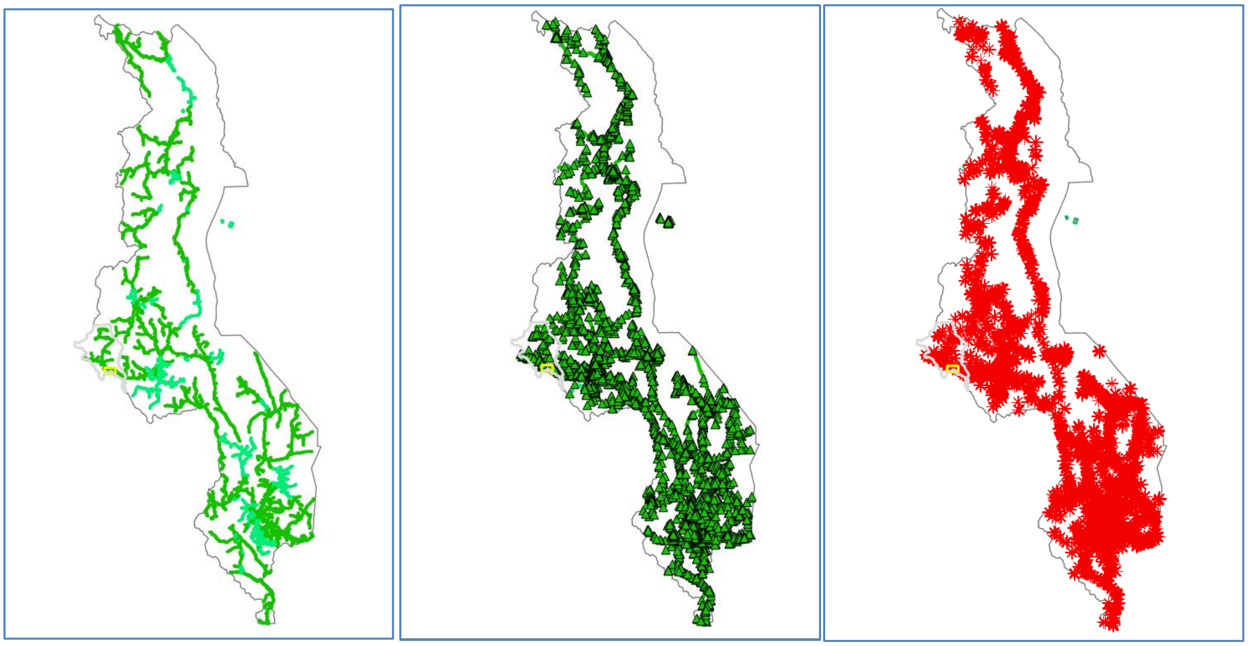


Figure 10: Geolocated 11 & 33 kV lines (left); transformers (center); and connections (right) to the ESCOM grid.

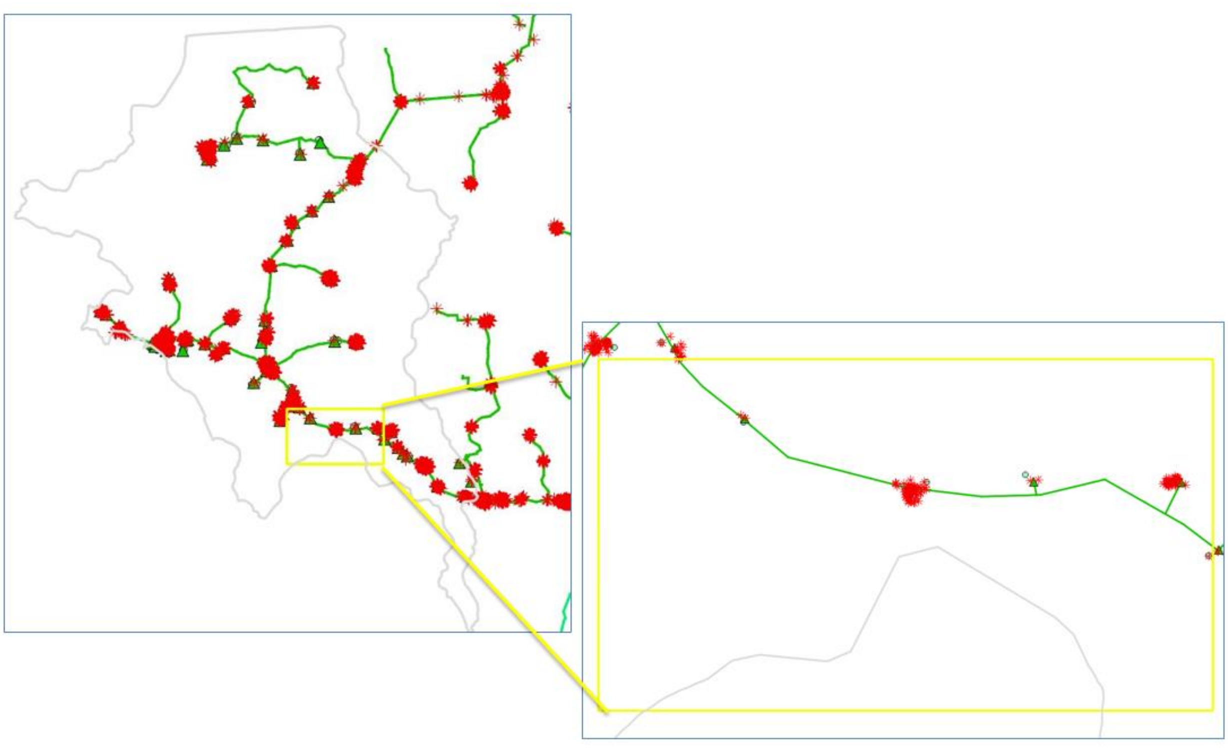


Figure 11: Data for ESCOM grid lines, transformers and connections (Mchinji District & local area)

4.3 Quantitative technical and cost parameters

As described in the Interim Report, quantitative and cost parameters related to grid extension and connections are a critical input for both a "first-order" geospatial plan, and more detailed analyses in the future. This information was gathered from the following three key sources: i) engineers and others in ESCOM (Blantyre) system planning and the Commercial Department; ii) private sector project developers familiar with grid extension through MAREP; iii) NGOs and other groups with experience constructing and operating mini-grids with technical standards roughly comparable with those of ESCOM.

However, these cost parameters have been difficult to capture with certainty, with reported values varying by a factor of two or three. This range and uncertainty is likely for a number of reasons: the decentralized manner of procurement and implementation of grid electrification projects; the resulting difficulty in finding a single source of comprehensive information or examples with the full costs and technical detail for entire projects; changing exchange rates that make cost data outdated; the tendency for different projects to include or exclude key costs (labor, transport, VAT, import duties, etc.); current conditions in which few projects are implemented, typically in a "bespoke" manner and at limited scale' and high costs per connection due to low penetration rates for connections, resulting in full initial costs for a grid "backbone" being spread across relatively few connections.

The final two points – the tendency for costs per connection to be high due to low penetration rites – was a focus of discussions with ESCOM during which ESCOM confirmed that the costs listed in its Commercial Department plans consider only the earliest phases of grid extension, when penetration rates are still very low. These low penetration rates result in long unit distances – lengths of MV and LV line per connection – since grid lines are divided among few customers. Cost modeling addressed this by considering two "scenarios":

- An estimate based on costs obtained primarily from ESCOM Commercial, which provided costs estimates indicating different costs for implementation at scale for "low, medium and high density" urban areas;
- A "high penetration" scenario, assuming shorter MV and LV distances per connection.

The two cost scenarios are summarized in Figure 12 below (and were presented previously in this document).

	Best guess estimate	Cost Est. for Sample Connection ESCOM Commercial						Cost Est. for Sample Connection High Penetration Scenario					
Notes		**m**	**Urban**	**m**	**Peri-Urban**	**m**	**Rural**	**m**	**Urban**	**m**	**Peri-Urban**	**m**	**Rural**
MV/KM (33 kV)	$13,000	10	$143	13	$390	43	$520	10	$143	13	$390	20	$520
LV (3ph)	$10,000	32	$320	33	$330	57	$570	20	$200	20	$200	25	$250
Connection (Avg)	$150		$150		$150		$150		$150		$150		$150
Extra Pole	$81				$16		$27				$16		$27
Total			**$580**		**$886**		**$1,267**		**$460**		**$756**		**$947**
ESCOM Reference			$559		$612.00		$1,327						
ESCOM Connection Type / Description		Urban "High Density"		Urban "Medium Denisty"		Urban "Low Density"							

Figure 12: Grid cost metrics for two scenarios: ESCOM Commercial Dept. & High Penetration

The left-most cost column contains the unit costs per km for MV line, LV line, as well as costs for the customer connection, and the cost of an extra pole for unusually long service drops. These costs are multiplied by various factors in the following two sets of columns to the right resulting in a cost "build up" for typical connections in dense ("urban"), medium density ("peri-urban) and low-density ("rural") geographies. These sets of household cost estimates are grouped according to two "scenarios":

- The "ESCOM Commercial" scenario is based on distances of MV and LV per connection sourced from ESCOM's plans which estimate very low coverage rates in the short-term;
- The "High Penetration" scenario includes much lower assumed distances between homes and communities, assuming that penetration rates are much higher.

The result is a dramatic drop in costs per connection, from a range of US$580 - $1,270 per connection using current ESCOM Commercial department data to a lower range of $460 - $950 per connection when higher penetration rates are assumed. It should be stressed that these costs are estimates.

5 Geospatial Analysis

5.1 Assessing distance from existing distribution grid

Powerful first-order observations regarding electrification strategies can result from combining the two main geolocated datasets: populated places from HRSL and grid lines and transformers from ESCOM. This combination allows estimation of the distance (and cost) of grid extensions. Figure 13 below shows these data at a local scale.

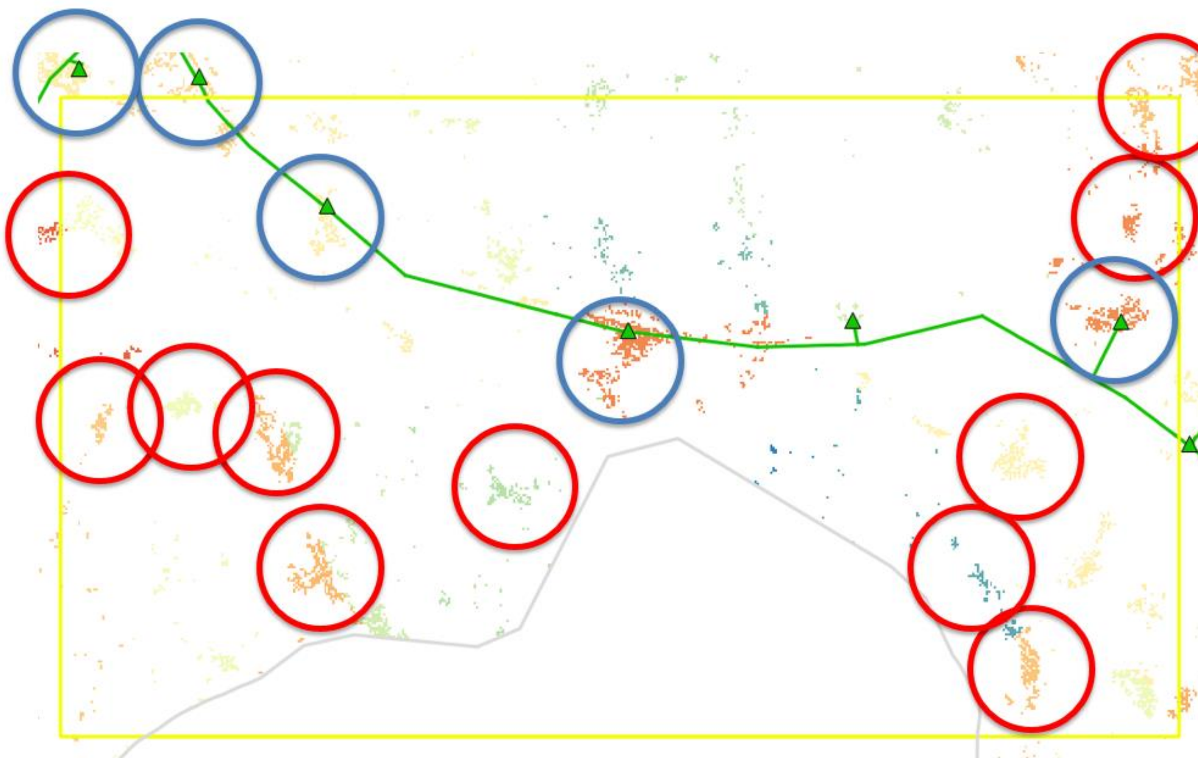


Figure 13: HRSL data for populated places with ESCOM data for existing grid. Blue circles show populated places in range of existing transformers; red circles show communities requiring medium voltage line extension.

This figure illustrates the planning challenge and potential benefit of a geospatial approach at the local scale. The clusters of colored pixels show HRSL gridded population estimates, with each color indicating a different estimated population per grid cell. These can be viewed as small towns, villages, or clusters of households, depending upon area and population density. The green lines and green triangles show locations for MV grid wires and service transformers, respectively. Areas immediately surrounding transformers – blue areas – will require only low voltage line, service drops and final connections to establish service. This is often referred to as "intensification" and is the lowest cost option to establish new grid access.

These data can offer insight into the important planning question of how to quantify the unconnected population and estimate costs to connect for those currently in range of existing transformers and lines. Areas beyond the range of existing transformers – red circles – will require investment to connect, either in the form of additional MV and LV lines for gird extension or alternate off-grid options such as mini-grids or solar home systems. The combination of geospatial population and grid system data offer insight into the question of how to select systems, quantify costs and prioritize access for areas outside of transformer range.

The same basic approach can be applied at larger spatial scales, as shown in Figure 14 below.

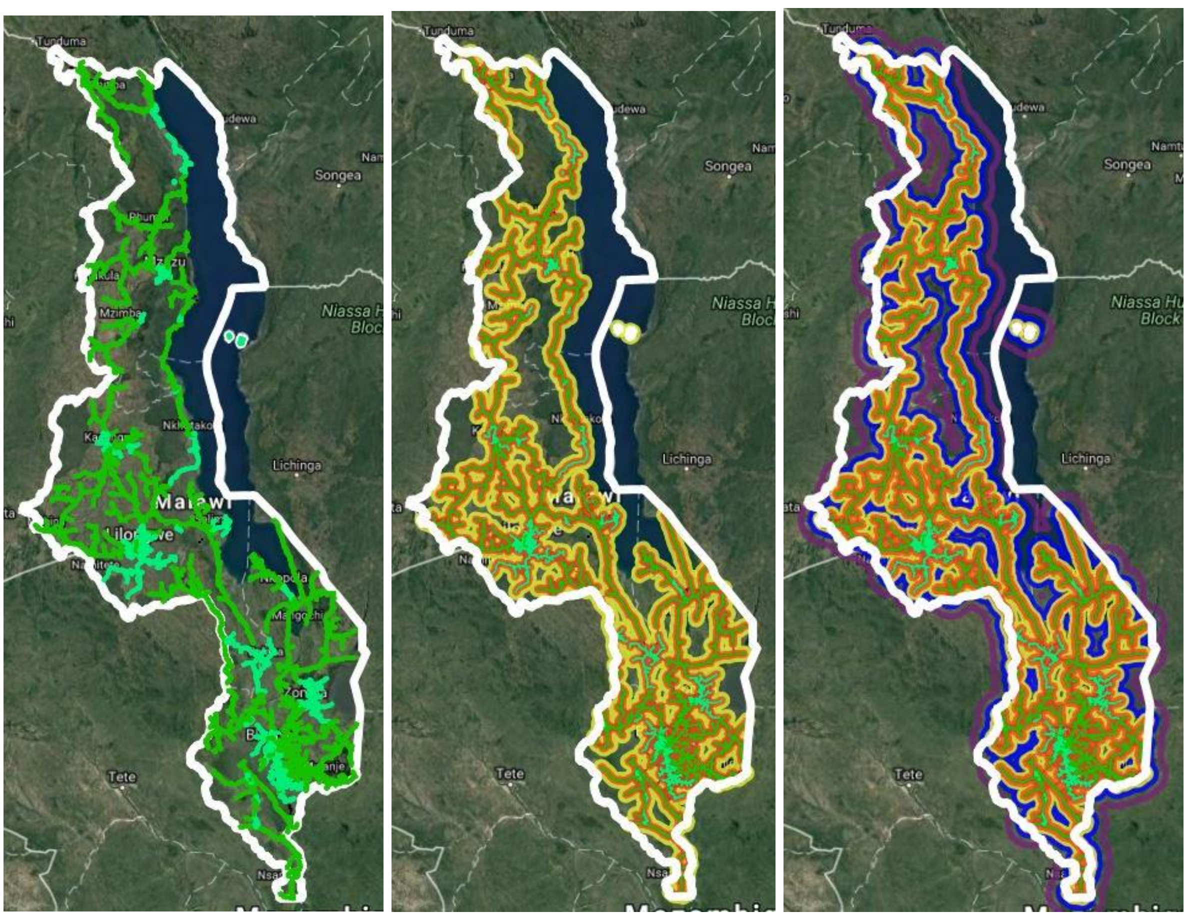


Figure 14: Existing ESCOM grid (left: green lines); Near grid: 1 -5 km (center: yellow, orange zones); Distant from grid: 10 -20 km (right: blue, violet zones)

Considering the first point above and going beyond simply estimating the total number of households within range of the grid, the potential for intensification, or connecting the *unconnected* population in transformer range, has been addressed in the following way: The ESCOM dataset provides geolocated data for individual connections. This is compared with the total estimated population (from HRSL) within a given range of the transformer. The difference provides an estimate of unconnected population. The specific locations for intensification, with prioritization by size, is presented in Figure 15 below.

- The green circles represent areas within 500 m of existing transformers.
- Red and white points are colored according point size (for red points it is estimated that at least 500 people (~100 households) remain unconnected).
- Numerical values represent unconnected population.

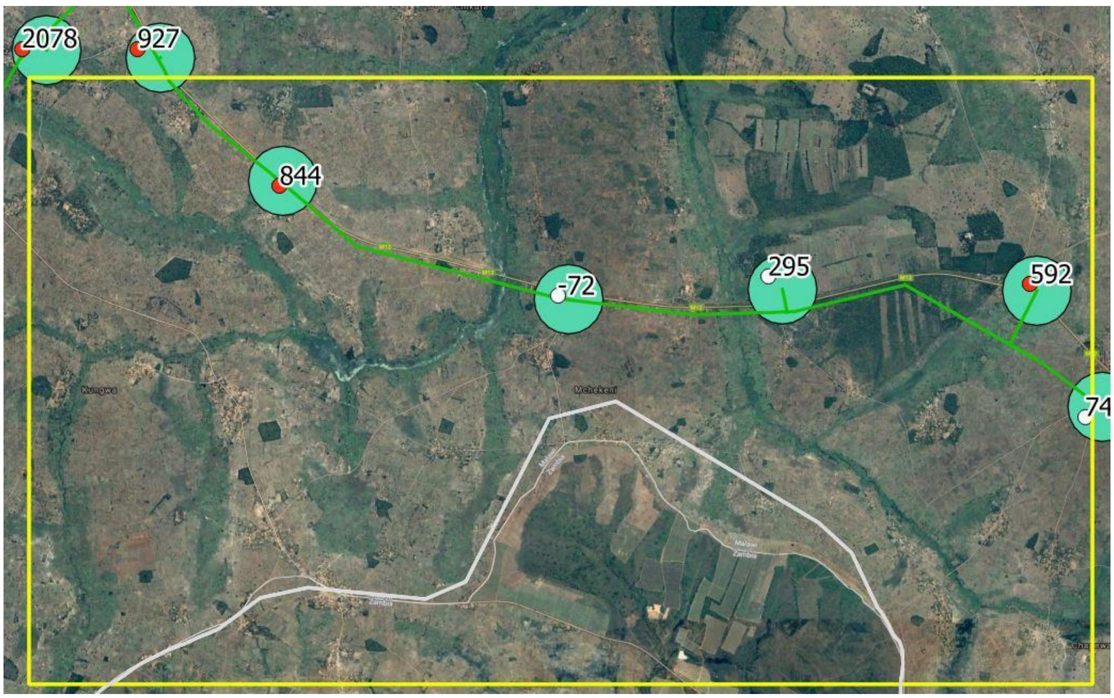


Figure 15: Estimating potential for intensification (local scale example)

5.2 Assessing priority locations for grid extension and off-grid systems

Another key task highlighted in the ToR is the identification of priority sites for a small number of off-grid systems. Taking a least-cost approach suggests that off-grid systems, such as mini-grids and solar home systems, should be targeted for areas and communities which are unlikely to get grid access soon (5-10 years). Figure 16 below suggests a preliminary methodology tested for Mchinji District.

- The left panel of the figure shows estimated transformer locations, derived from HRSL. Red points having higher population and blue points having lower population. The green lines indicate the distance from each point to the closest location on the existing grid.
- The right panel shows the same data, but the 80% of points with smaller population (blue, green, yellow, orange) are all removed only the 20% of the transformer points with the highest population (red, orange) remain – in effect, the highest priority locations for electricity service.

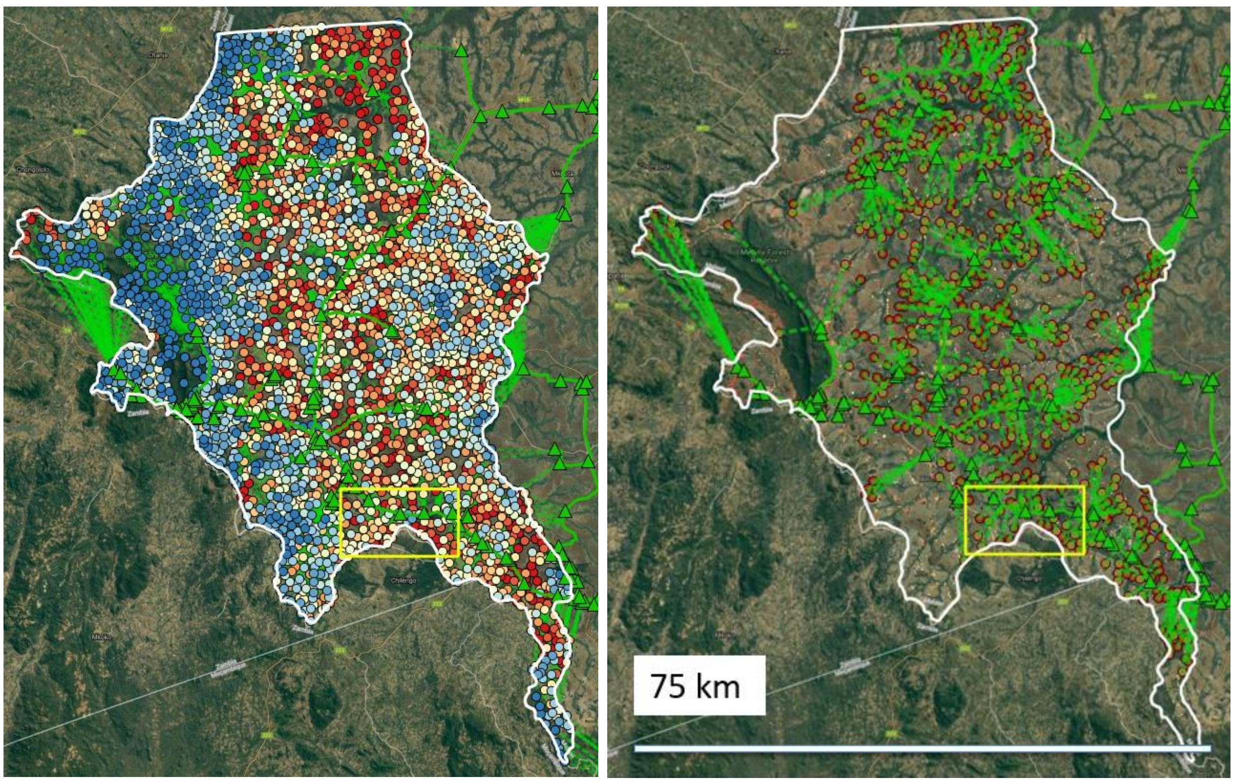


Figure 16: Left: All estimated transformer locations (points) with distances to grid (lines); Right: selected points (in red) with high population for prioritized electricity access.

Considering only the right panel of the figure, many of the red, high population points, are close to the existing ESCOM grid – but not all. Those high population points that are unusually distant from the grid will likely make the most cost-effective sites for implementation of off-grid systems. An enlarged portion of Mchinji District is shown in Figure 17 below, indicating a cluster of points that are very far from existing grid (more than 20 km) and also have high populations, making them good candidates for consideration in off-grid system planning.

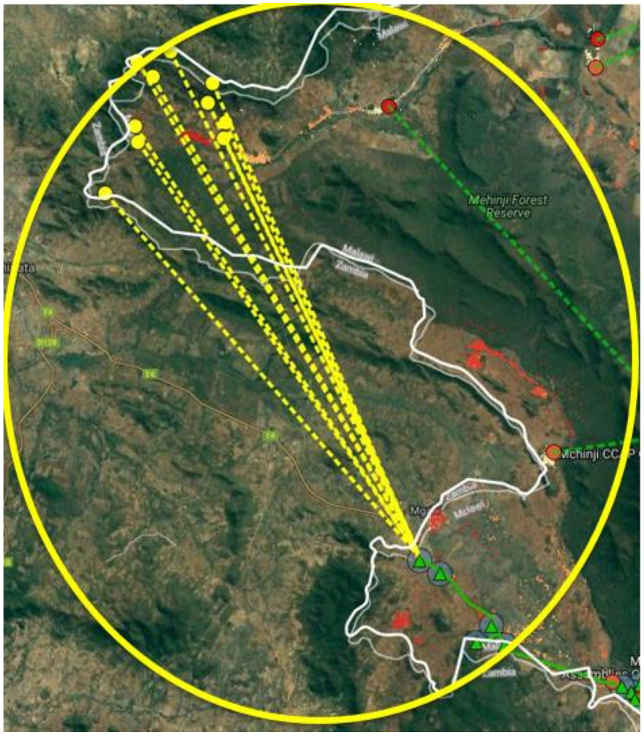


Figure 17: Western point of Mchinji District indicating a cluster of locations far from the grid which may make ideal target sites for off-grid systems.

5.3 Preliminary methodology to prioritize MAREP trading centres

In addition to the approaches described above – focused on prioritization of grid connection and off-grid sites – there is also potential to use GIS techniques to help prioritize among and estimate costs for electrification of trading centres under the Malawi Rural Electrification Program (MAREP). MAREP plans grid electrification by identifying, characterizing and then prioritizing among rural trading centres. In a meeting in February of 2018, MAREP leadership expressed that they would be interested in using geospatial quantitative methods to help quantify costs and prioritize among the trading centres being considered for grid extension. In that meeting, MAREP provided geolocated trading centre data for only one district (Chiradzulu) and encouraged the Millennium Promise team to investigate how geospatial techniques might be used to assist in planning.

The preliminary analysis of the Chiradzulu District data focused on many of the same techniques described above, including combination of geolocated population and grid data, and distance calculations between demand and supply. The added detail is the inclusion of trading centres as priority locations for grid extension. The steps of the approach are presented in Figure 18 below. The left panel shows all potential transformer locations (~1,100 green points) in the Chiradzulu District, as derived from HRSL, along with all trading centres (46 TCs) identified and geolocated by MAREP. The center panel shows a selection of the 20% of the transformer locations with the highest population (17 red points) along with those TCs within 500 m (red triangles). The right panel shows only this sub-set of 17 TCs (the populated places / transformer locations have been removed for clarity).

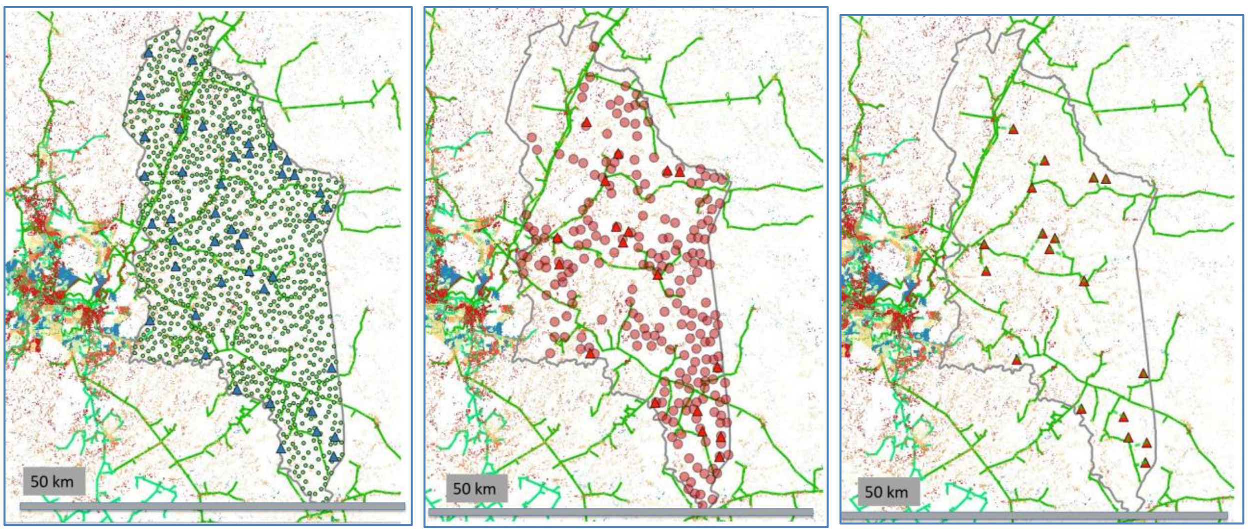


Figure 18: Geospatial approach to prioritizing trading centers (TCs) for MAREP. Left to right: all populated places and TCs; settlements with high population and nearby TCs; only 17 prioritized TCs.

The examples presented in this section provide approaches to key needs of the utility and of off-grid project planners, including validation of current plans for grid extension; prioritization and quantification of grid extension plans in the near term (2-5 years); and identification of potential sites for off-grid systems. It could be of benefit to ESCOM and MAREP planners, among others, to learn to apply these GIS techniques in their daily work to bring more geospatial and quantitative clarity and rigor to planning.

Annexes

Annex A: Population and Distance from the grid, Nationwide and by Region

Population with Distance from Grid, totals and percentages, Natiowide and by Region		2018		2020		2025		2030	
Distance to existing MV lines (km)	**All Regions**	**18,754,618**	**Cumul.**	**19,934,753**	**Cumul.**	**23,203,091**	**Cumul.**	**26,941,610**	**Cumul.**
	1	8,307,410	44%	8,884,699	45%	10,485,104	45%	12,320,341	46%
	2.5	3,620,618	64%	3,821,947	64%	4,379,121	64%	5,011,928	64%
	5	3,528,970	82%	3,732,130	82%	4,294,372	83%	4,936,043	83%
	10	2,607,002	96%	2,762,357	96%	3,192,190	96%	3,684,893	96%
	15	510,460	99%	542,260	99%	630,215	99%	731,303	99%
	20	133,873	100%	142,374	100%	165,806	100%	192,644	100%
	25	35,429	100%	37,553	100%	43,318	100%	49,808	100%
	>25	10,857	100%	11,431	100%	12,966	100%	14,651	100%
Distance to existing MV lines (km)	**Central**	**8,159,779**	**Cumul.**	**8,728,834**	**Cumul.**	**10,308,088**	**Cumul.**	**12,139,146**	**Cumul.**
	1	3,283,694	40%	3,547,752	41%	4,281,406	42%	5,131,634	42%
	2.5	1,420,989	58%	1,511,052	58%	1,760,655	59%	2,049,871	59%
	5	1,747,890	79%	1,856,866	79%	2,158,752	80%	2,508,694	80%
	10	1,426,727	97%	1,514,423	97%	1,757,606	97%	2,039,762	97%
	15	242,533	100%	257,970	100%	300,951	100%	351,067	100%
	20	34,094	100%	36,633	100%	43,779	100%	52,233	100%
	25	3,850	100%	4,135	100%	4,936	100%	5,882	100%
	>25	2	100%	2	100%	3	100%	3	100%
Distance to existing MV lines (km)	**Northern**	**2,524,804**	**Cumul.**	**2,683,269**	**Cumul.**	**3,107,911**	**Cumul.**	**3,580,184**	**Cumul.**
	1	1,052,681	42%	1,129,003	42%	1,336,922	43%	1,572,894	44%
	2.5	434,400	59%	459,513	59%	526,340	60%	599,791	61%
	5	394,144	75%	416,142	75%	474,172	75%	537,385	76%
	10	420,343	91%	443,361	91%	503,813	91%	569,455	92%
	15	136,203	97%	143,577	97%	162,882	97%	183,788	97%
	20	57,400	99%	60,472	99%	68,494	99%	77,171	99%
	25	22,431	100%	23,619	100%	26,717	100%	30,061	100%
	>25	7,202	100%	7,582	100%	8,572	100%	9,640	100%
Distance to existing MV lines (km)	**Southern**	**8,070,035**	**Cumul.**	**8,522,651**	**Cumul.**	**9,787,092**	**Cumul.**	**11,222,280**	**Cumul.**
	1	3,971,035	49%	4,207,944	49%	4,866,776	50%	5,615,813	50%
	2.5	1,765,230	71%	1,851,382	71%	2,092,125	71%	2,362,267	71%
	5	1,386,935	88%	1,459,122	88%	1,661,448	88%	1,889,964	88%
	10	759,931	98%	804,574	98%	930,771	98%	1,075,675	98%
	15	131,724	99%	140,713	99%	166,383	99%	196,447	99%
	20	42,379	100%	45,269	100%	53,533	100%	63,241	100%
	25	9,148	100%	9,799	100%	11,665	100%	13,865	100%
	>25	3,653	100%	3,847	100%	4,392	100%	5,008	100%

Annex B: Population with Distance from Grid, totals & percentages, by District

Population with Distance from Grid, totals and percentages, by District								
District	Population (est.)		Population (est.)		Population (est.)		Population (est.)	
km from grid	2018		2020		2025		2030	
National Total	**18,754,618**		**19,934,753**		**23,203,091**		**26,941,610**	
Balaka	**443,710**		**473,157**		**556,230**		**652,497**	
1 km	162,510	37%	173,296	37%	203,722	37%	238,980	37%
2.5 km	99,513	59%	106,117	59%	124,748	59%	146,338	59%
5 km	112,477	84%	119,942	84%	141,001	84%	165,404	84%
10 km	69,209	100%	73,803	100%	86,760	100%	101,776	100%
Blantyre	**421,880**		**441,423**		**493,803**		**549,864**	
1 km	179,103	42%	187,400	42%	209,637	42%	233,437	42%
2.5 km	114,133	70%	119,421	70%	133,591	70%	148,758	70%
5 km	99,437	93%	104,043	93%	116,389	93%	129,603	93%
10 km	28,395	100%	29,711	100%	33,236	100%	37,010	100%
15 km	811	100%	849	100%	949	100%	1,057	100%
Blantyre City	**936,414**		**1,009,615**		**1,209,335**		**1,436,864**	
1 km	926,980	99%	999,442	99%	1,197,150	99%	1,422,388	99%
2.5 km	9,435	100%	10,172	100%	12,184	100%	14,477	100%
Chikwawa	**588,087**		**623,840**		**723,553**		**837,494**	
1 km	249,459	42%	264,626	42%	306,922	42%	355,255	42%
2.5 km	89,378	58%	94,812	58%	109,966	58%	127,283	58%
5 km	136,641	81%	144,948	81%	168,116	81%	194,590	81%
10 km	87,060	96%	92,353	96%	107,114	96%	123,982	96%
15 km	19,860	99%	21,067	99%	24,435	99%	28,282	99%
20 km	4,966	100%	5,268	100%	6,110	100%	7,072	100%
25 km	724	100%	768	100%	890	100%	1,030	100%
Chiradzulu	**364,471**		**374,415**		**400,537**		**427,005**	
1 km	191,053	52%	196,266	52%	209,959	52%	223,834	52%
2.5 km	147,550	93%	151,576	93%	162,151	93%	172,866	93%
5 km	25,867	100%	26,573	100%	28,427	100%	30,305	100%
Chitipa	**262,627**		**276,488**		**312,577**		**351,518**	
1 km	92,210	35%	97,076	35%	109,747	35%	123,420	35%
2.5 km	55,589	56%	58,523	56%	66,162	56%	74,404	56%
5 km	44,615	73%	46,970	73%	53,100	73%	59,716	73%
10 km	38,356	88%	40,380	88%	45,651	88%	51,338	88%
15 km	17,623	95%	18,553	95%	20,975	95%	23,588	95%
20 km	7,337	97%	7,725	97%	8,733	97%	9,821	97%
25 km	3,054	99%	3,215	99%	3,634	99%	4,087	99%
>25 km	3,844	100%	4,046	100%	4,575	100%	5,145	100%

Population with Distance from Grid, totals and percentages, by District								
District km from grid	**Population (est.) 2018**		**Population (est.) 2020**		**Population (est.) 2025**		**Population (est.) 2030**	
Dedza	**853,493**		**893,642**		**1,003,894**		**1,127,307**	
1 km	242,982	28%	254,411	28%	285,799	28%	320,934	28%
2.5 km	169,330	48%	177,295	48%	199,169	48%	223,653	48%
5 km	221,646	74%	232,073	74%	260,704	74%	292,754	74%
10 km	186,992	96%	195,788	96%	219,943	96%	246,982	96%
15 km	32,518	100%	34,047	100%	38,248	100%	42,950	100%
20 km	26	100%	27	100%	30	100%	34	100%
Dowa	**832,869**		**902,131**		**1,090,631**		**1,307,765**	
1 km	227,130	27%	246,018	27%	297,424	27%	356,638	27%
2.5 km	193,335	50%	209,413	50%	253,170	50%	303,574	50%
5 km	243,517	80%	263,768	80%	318,883	80%	382,369	80%
10 km	154,778	98%	167,649	98%	202,679	98%	243,031	98%
15 km	14,109	100%	15,282	100%	18,476	100%	22,154	100%
Karonga	**398,900**		**423,975**		**493,032**		**571,281**	
1 km	217,653	55%	231,334	55%	269,014	55%	311,709	55%
2.5 km	100,236	80%	106,537	80%	123,890	80%	143,552	80%
5 km	44,697	91%	47,506	91%	55,244	91%	64,012	91%
10 km	30,606	99%	32,529	99%	37,828	99%	43,831	99%
15 km	4,512	100%	4,796	100%	5,577	100%	6,462	100%
20 km	1,148	100%	1,220	100%	1,419	100%	1,644	100%
25 km	49	100%	52	100%	61	100%	71	100%
Kasungu	**914,397**		**986,066**		**1,188,552**		**1,429,447**	
1 km	273,628	30%	295,075	30%	355,668	30%	427,754	30%
2.5 km	163,753	48%	176,587	48%	212,849	48%	255,989	48%
5 km	199,634	70%	215,281	70%	259,489	70%	312,082	70%
10 km	191,081	91%	206,057	91%	248,371	91%	298,710	91%
15 km	63,946	98%	68,957	98%	83,118	98%	99,964	98%
20 km	20,395	100%	21,994	100%	26,510	100%	31,883	100%
25 km	1,960	100%	2,114	100%	2,548	100%	3,065	100%
>25 km	0	100%	0	100%	0	100%	0	100%
Likoma	**13,615**		**13,653**		**13,751**		**13,778**	
1 km	13,615	100%	13,653	100%	13,751	100%	13,778	100%

Population with Distance from Grid, totals and percentages, by District

District km from grid	Population (est.) 2018		Population (est.) 2020		Population (est.) 2025		Population (est.) 2030	
Lilongwe	**1,734,089**		**1,819,745**		**2,058,874**		**2,336,025**	
1 km	436,353	25%	457,907	25%	518,079	25%	587,819	25%
2.5 km	373,471	47%	391,919	47%	443,420	47%	503,111	47%
5 km	465,364	74%	488,351	74%	552,524	74%	626,901	74%
10 km	409,199	97%	429,412	97%	485,840	97%	551,240	97%
15 km	49,480	100%	51,924	100%	58,747	100%	66,656	100%
20 km	219	100%	230	100%	260	100%	295	100%
25 km	2	100%	2	100%	3	100%	3	100%
Lilongwe City	**1,243,690**		**1,382,945**		**1,770,739**		**2,220,208**	
1 km	1,192,633	96%	1,326,172	96%	1,698,046	96%	2,129,063	96%
2.5 km	37,880	99%	42,121	99%	53,932	99%	67,622	99%
5 km	10,804	100%	12,014	100%	15,383	100%	19,287	100%
10 km	2,373	100%	2,638	100%	3,378	100%	4,236	100%
Machinga	**698,006**		**743,177**		**872,644**		**1,024,466**	
1 km	233,311	33%	248,410	33%	291,684	33%	342,431	33%
2.5 km	148,948	55%	158,587	55%	186,215	55%	218,612	55%
5 km	158,104	77%	168,336	77%	197,661	77%	232,050	77%
10 km	133,956	97%	142,625	97%	167,471	97%	196,608	97%
15 km	22,195	100%	23,632	100%	27,749	100%	32,576	100%
20 km	1,354	100%	1,441	100%	1,693	100%	1,987	100%
25 km	137	100%	146	100%	171	100%	201	100%
Mangochi	**1,213,987**		**1,302,465**		**1,556,809**		**1,857,412**	
1 km	516,637	43%	554,290	43%	662,531	43%	790,459	43%
2.5 km	233,485	62%	250,502	62%	299,420	62%	357,235	62%
5 km	164,152	75%	176,116	75%	210,508	75%	251,154	75%
10 km	179,730	90%	192,829	90%	230,485	90%	274,989	90%
15 km	79,454	97%	85,245	97%	101,891	97%	121,566	97%
20 km	30,925	99%	33,178	99%	39,658	99%	47,315	99%
25 km	8,000	100%	8,583	100%	10,259	100%	12,240	100%
>25 km	1,604	100%	1,721	100%	2,057	100%	2,454	100%
Mchinji	**690,494**		**739,961**		**878,417**		**1,041,772**	
1 km	209,641	30%	224,660	30%	266,697	30%	316,293	30%
2.5 km	112,401	47%	120,453	47%	142,991	47%	169,583	47%
5 km	166,366	71%	178,284	71%	211,644	71%	251,002	71%
10 km	168,115	95%	180,158	95%	213,868	95%	253,640	95%
15 km	23,669	99%	25,364	99%	30,110	99%	35,710	99%
20 km	8,856	100%	9,490	100%	11,266	100%	13,361	100%
25 km	1,447	100%	1,551	100%	1,841	100%	2,184	100%

Population with Distance from Grid, totals and percentages, by District								
District	**Population (est.)**		**Population (est.)**		**Population (est.)**		**Population (est.)**	
km from grid	**2018**		**2020**		**2025**		**2030**	
Mulanje	**666,516**		**684,769**		**734,425**		**786,519**	
1 km	295,666	44%	303,763	44%	325,791	44%	348,900	44%
2.5 km	199,227	74%	204,683	74%	219,526	74%	235,097	74%
5 km	139,768	95%	143,595	95%	154,008	95%	164,932	95%
10 km	31,854	100%	32,727	100%	35,100	100%	37,590	100%
15 km	0	100%	0	100%	0	100%	0	100%
Mwanza	**135,249**		**139,255**		**149,000**		**158,157**	
1 km	76,206	56%	78,463	56%	83,954	56%	89,113	56%
2.5 km	33,055	81%	34,033	81%	36,415	81%	38,653	81%
5 km	23,245	98%	23,934	98%	25,609	98%	27,182	98%
10 km	2,740	100%	2,821	100%	3,019	100%	3,204	100%
15 km	3	100%	3	100%	3	100%	4	100%
Mzimba	**1,063,573**		**1,119,707**		**1,265,857**		**1,423,558**	
1 km	252,115	24%	265,421	24%	300,065	24%	337,448	24%
2.5 km	159,850	39%	168,287	39%	190,253	39%	213,954	39%
5 km	202,479	58%	213,166	58%	240,989	58%	271,012	58%
10 km	281,215	84%	296,057	84%	334,700	84%	376,397	84%
15 km	99,730	94%	104,994	94%	118,698	94%	133,486	94%
20 km	45,758	98%	48,173	98%	54,461	98%	61,245	98%
25 km	19,067	100%	20,073	100%	22,693	100%	25,521	100%
>25 km	3,358	100%	3,536	100%	3,997	100%	4,495	100%
Mzuzu City	**241,749**		**272,629**		**359,634**		**463,029**	
1 km	236,033	98%	266,184	98%	351,132	98%	452,082	98%
2.5 km	5,715	100%	6,445	100%	8,502	100%	10,946	100%
Neno	**170,353**		**186,243**		**229,924**		**278,663**	
1 km	60,252	35%	65,873	35%	81,322	35%	98,561	35%
2.5 km	42,859	61%	46,857	61%	57,847	61%	70,109	61%
5 km	41,621	85%	45,503	85%	56,175	85%	68,083	85%
10 km	23,328	99%	25,504	99%	31,486	99%	38,160	99%
15 km	2,292	100%	2,506	100%	3,093	100%	3,749	100%
Nkhata Bay	**295,736**		**315,088**		**367,156**		**424,231**	
1 km	122,913	42%	130,956	42%	152,597	42%	176,318	42%
2.5 km	59,112	62%	62,981	62%	73,388	62%	84,796	62%
5 km	58,801	81%	62,648	81%	73,001	81%	84,349	81%
10 km	41,344	95%	44,050	95%	51,329	95%	59,308	95%
15 km	11,005	99%	11,725	99%	13,662	99%	15,786	99%
20 km	2,268	100%	2,417	100%	2,816	100%	3,254	100%
25 km	292	100%	312	100%	363	100%	420	100%

Population with Distance from Grid, totals and percentages, by District								
District km from grid	Population (est.) 2018		Population (est.) 2020		Population (est.) 2025		Population (est.) 2030	
Nkhotakota	**437,217**		**465,331**		**544,071**		**634,840**	
1 km	180,961	41%	192,597	41%	225,186	41%	262,755	41%
2.5 km	99,175	64%	105,552	64%	123,413	64%	144,002	64%
5 km	97,126	86%	103,372	86%	120,863	86%	141,027	86%
10 km	53,916	99%	57,383	99%	67,093	99%	78,286	99%
15 km	2,103	99%	2,238	99%	2,617	99%	3,053	99%
20 km	3,525	100%	3,752	100%	4,387	100%	5,119	100%
25 km	409	100%	435	100%	509	100%	594	100%
>25 km	2	100%	2	100%	3	100%	3	100%
Nsanje	**319,255**		**335,777**		**382,428**		**437,090**	
1 km	189,065	59%	198,849	59%	226,476	59%	258,847	59%
2.5 km	60,333	78%	63,456	78%	72,272	78%	82,602	78%
5 km	42,319	91%	44,509	91%	50,693	91%	57,939	91%
10 km	20,938	98%	22,022	98%	25,082	98%	28,667	98%
15 km	2,481	99%	2,609	99%	2,972	99%	3,397	99%
20 km	3,832	100%	4,030	100%	4,590	100%	5,247	100%
25 km	286	100%	301	100%	343	100%	392	100%
Ntcheu	**641,772**		**676,170**		**768,914**		**873,952**	
1 km	202,836	32%	213,708	32%	243,020	32%	276,218	32%
2.5 km	110,538	49%	116,463	49%	132,437	49%	150,528	49%
5 km	160,999	74%	169,628	74%	192,894	74%	219,245	74%
10 km	155,058	98%	163,369	98%	185,777	98%	211,155	98%
15 km	12,308	100%	12,968	100%	14,746	100%	16,761	100%
20 km	32	100%	34	100%	39	100%	44	100%
Ntchisi	**328,038**		**350,148**		**411,624**		**484,597**	
1 km	88,144	27%	94,085	27%	110,604	27%	130,212	27%
2.5 km	65,907	47%	70,349	47%	82,701	47%	97,362	47%
5 km	97,852	77%	104,447	77%	122,785	77%	144,552	77%
10 km	58,125	95%	62,042	95%	72,935	95%	85,865	95%
15 km	17,236	100%	18,397	100%	21,628	100%	25,462	100%
20 km	775	100%	827	100%	972	100%	1,144	100%
Phalombe	**426,891**		**450,035**		**517,221**		**593,975**	
1 km	173,490	41%	182,896	41%	210,200	41%	241,393	41%
2.5 km	112,633	67%	118,739	67%	136,466	67%	156,717	67%
5 km	103,134	91%	108,725	91%	124,957	91%	143,500	91%
10 km	37,454	100%	39,485	100%	45,380	100%	52,114	100%
15 km	180	100%	190	100%	218	100%	251	100%

Population with Distance from Grid, totals and percentages, by District								
District **km from grid**	**Population (est.)** **2018**		**Population (est.)** **2020**		**Population (est.)** **2025**		**Population (est.)** **2030**	
Rumphi	**248,751**		**261,879**		**296,061**		**332,945**	
1 km	118,053	47%	124,284	47%	140,506	47%	158,010	47%
2.5 km	53,917	69%	56,763	69%	64,172	69%	72,167	69%
5 km	43,613	87%	45,915	87%	51,908	87%	58,374	87%
10 km	28,808	98%	30,329	98%	34,287	98%	38,559	98%
15 km	3,372	100%	3,550	100%	4,013	100%	4,513	100%
20 km	987	100%	1,039	100%	1,175	100%	1,321	100%
25 km	0	100%	0	100%	0	100%	0	100%
>25 km	0	100%	0	100%	0	100%	0	100%
Salima	**484,268**		**513,261**		**592,991**		**683,909**	
1 km	229,471	47%	243,209	47%	280,989	47%	324,071	47%
2.5 km	95,149	67%	100,846	67%	116,511	67%	134,375	67%
5 km	84,761	85%	89,835	85%	103,790	85%	119,704	85%
10 km	47,628	94%	50,480	94%	58,321	94%	67,263	94%
15 km	27,102	100%	28,724	100%	33,186	100%	38,275	100%
20 km	157	100%	167	100%	192	100%	222	100%
Thyolo	**794,002**		**823,490**		**906,172**		**995,690**	
1 km	319,017	40%	330,865	40%	364,085	40%	400,052	40%
2.5 km	243,095	71%	252,123	71%	277,438	71%	304,845	71%
5 km	157,708	91%	163,565	91%	179,988	91%	197,769	91%
10 km	70,373	100%	72,986	100%	80,315	100%	88,249	100%
15 km	3,809	100%	3,950	100%	4,347	100%	4,776	100%
Zomba	**761,694**		**790,370**		**867,937**		**949,473**	
1 km	269,469	35%	279,614	35%	307,055	35%	335,901	35%
2.5 km	231,607	66%	240,327	66%	263,913	66%	288,705	66%
5 km	182,223	90%	189,083	90%	207,640	90%	227,146	90%
10 km	74,369	99%	77,168	99%	84,742	99%	92,703	99%
15 km	663	100%	688	100%	756	100%	827	100%
20 km	1,313	100%	1,362	100%	1,496	100%	1,637	100%
25 km	1	100%	1	100%	1	100%	1	100%
>25 km	2,049	100%	2,126	100%	2,335	100%	2,554	100%
Zomba City	**128,826**		**143,904**		**186,300**		**236,279**	
1 km	128,819	100%	143,896	100%	186,289	100%	236,266	100%
2.5 km	7	100%	8	100%	10	100%	13	100%

Annex C: High Priority Project Locations with Household Estimate, by TA or SC

High Priority Locations with Household estimate, by TA or SC

District	Locations	Unconnected Households (est.)			
TA / SC		2018	2020	2025	2030
National Total	**109**	**111,009**	**119,484**	**143,216**	**170,753**
Central	**45**	**40,325**	**43,685**	**53,009**	**63,781**
Dedza	**8**	**5,015**	**5,251**	**5,898**	**6,624**
SC Kamenya Gwaza	1	630	660	742	833
TA Kachindamoto	2	1,315	1,377	1,547	1,737
TA Kasumbu	2	1,462	1,531	1,720	1,932
TA Pemba	2	1,090	1,141	1,282	1,440
TA Tambala	1	517	541	608	682
Dowa	**5**	**3,492**	**3,783**	**4,573**	**5,483**
Mponela Urban	1	933	1,010	1,221	1,464
SC Chakhaza	1	737	798	965	1,157
SC Kayembe	1	556	602	728	873
SC Mkukula	1	744	806	975	1,169
TA Dzoole	1	522	565	684	820
Lilongwe	**17**	**22,114**	**24,331**	**30,505**	**37,661**
Lilongwe City	10	17,966	19,977	25,579	32,072
TA Chadza	1	627	658	745	845
TA Chimutu	1	531	557	631	716
TA Chiseka	2	1,212	1,272	1,439	1,633
TA Kalolo	2	1,253	1,315	1,488	1,688
TA Malili	1	525	551	623	707
Mchinji	**4**	**2,869**	**3,074**	**3,650**	**4,328**
Mchinji Boma	1	922	988	1,173	1,391
SC Dambe	1	691	741	879	1,043
TA Mkanda	1	638	684	812	962
TA Zulu	1	618	662	786	932
Nkhotakota	5	2,761	2,938	3,436	4,009
Lake Malawi	1	520	553	647	755
Nkhotakota Boma	1	563	599	701	817
TA Kanyenda	3	1,678	1,786	2,088	2,437
Ntcheu	3	1,535	1,617	1,839	2,090
SC Goodson Ganya	1	501	528	601	683
TA Chakhumbira	1	506	533	606	689
TA Njolomole	1	528	556	632	719
Salima	3	2,539	2,691	3,109	3,586
Salima Town	1	1,375	1,457	1,683	1,941
TA Pemba	2	1,164	1,234	1,426	1,644

High Priority Locations with Household estimate, by TA or SC					
District	**Locations**	**Unconnected Households (est.)**			
TA / SC		**2018**	**2020**	**2025**	**2030**
Northern	**10**	**11,194**	**12,091**	**14,549**	**17,371**
Chitipa	**1**	**2,276**	**2,396**	**2,709**	**3,046**
Chitipa Boma	1	2,276	2,396	2,709	3,046
Karonga	**2**	**2,070**	**2,200**	**2,558**	**2,964**
Karonga Town	2	2,070	2,200	2,558	2,964
Mzimba	**5**	**5,662**	**6,247**	**7,871**	**9,774**
Mzimba Boma	1	504	530	599	674
Mzuzu City	3	3,805	4,291	5,661	7,288
TA Mtwalo	1	1,354	1,425	1,611	1,812
Rumphi	**2**	**1,186**	**1,248**	**1,411**	**1,587**
Rumphi Boma	1	551	580	656	738
TA Chikulamayembe	1	634	668	755	849

High Priority Locations with Household estimate, by TA or SC					
District	**Locations**	**Unconnected Households (est.)**			
TA / SC		**2018**	**2020**	**2025**	**2030**
Southern	**54**	**59,491**	**63,709**	**75,658**	**89,601**
Balaka	**2**	**2,036**	**2,171**	**2,552**	**2,994**
Balaka Town	2	2,036	2,171	2,552	2,994
Blantyre	**6**	**8,340**	**8,992**	**10,771**	**12,797**
Blantyre City	6	8,340	8,992	10,771	12,797
Chikwawa	**9**	**7,411**	**7,862**	**9,119**	**10,555**
TA Kasisi	1	778	826	958	1,108
TA Katunga	1	757	803	932	1,079
TA Lundu	5	4,856	5,151	5,975	6,916
TA Makhwira	1	500	531	615	712
TA Ngabu	1	520	551	639	740
Machinga	**2**	**1,583**	**1,686**	**1,979**	**2,324**
SC Chiwalo	1	972	1,035	1,215	1,427
TA Nyambi	1	611	651	764	897
Mangochi	**23**	**32,467**	**34,833**	**41,635**	**49,674**
Lake Malawi	4	19,710	21,147	25,276	30,157
SC Chowe	2	1,176	1,261	1,508	1,799
SC Namabvi	2	1,946	2,088	2,496	2,977
TA Chimwala	3	1,792	1,923	2,298	2,742
TA Jalasi	6	3,772	4,047	4,837	5,771
TA Makanjila	3	2,157	2,314	2,766	3,301
TA Mponda	2	1,059	1,136	1,358	1,621
TA Nankumba	1	854	916	1,095	1,306
Mulanje	**1**	**532**	**547**	**586**	**628**
SC Laston Njema	1	532	547	586	628
Neno	**2**	**1,136**	**1,242**	**1,533**	**1,858**
TA Ngozi	1	562	615	759	920
TA Symon	1	574	627	774	939
Nsanje	**5**	**3,162**	**3,326**	**3,788**	**4,329**
Nsanje Boma	3	2,059	2,166	2,467	2,819
SC Mbenje	1	575	604	688	787
TA Ndamera	1	528	555	632	723
Phalombe	**1**	**785**	**828**	**951**	**1,093**
TA Mkhumba	1	785	828	951	1,093
Thyolo	**1**	**670**	**695**	**765**	**840**
SC Mphuka	1	670	695	765	840
Zomba	**2**	**1,368**	**1,528**	**1,979**	**2,509**
Zomba City	2	1,368	1,528	1,979	2,509

Annex D: Selected Sites Meeting Off-grid "Pre-electrification" Criteria

This annex presents details and map images for off-grid "pre-electrification" candidate locations selected in two screening phases. The first phase selected sites that met two quantitative criteria: the population clusters reside at least 10 km from existing ESCOM lines (and thus highly likely to wait 5 years or more for grid connectivity) and populations of more than 750 (making it more likely to justify the effort for off-grid system installation and maintenance). A full list of all locations obtained in this first geospatial screening is presented in Table 12 on the following pages. Following this, a second screening selected eight candidate sites within 1 km of a health centre or dispensary, the two rural health facility types most likely to require electric power. Table 13 provides summary information for these sites, followed by wide area and close-up maps for each location in the pages that follow.

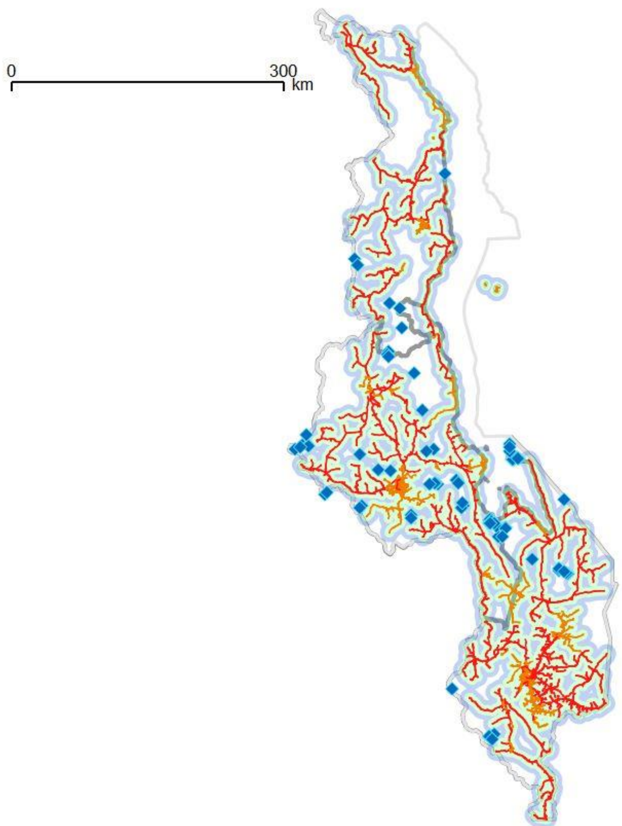


Figure 19: National map of 74 off-grid "pre-electrification" candidate sites selected in the first screening stage.

Table 12: Full list of all 74 off-grid "pre-electrification" candidate locations meeting the first two selection criteria: > 10 km from grid; > 750 population

	x	y	Population	Households	km to Grid	km to Trans-former	District	TA / SC	Region
1	34.67556	-14.27937	847.0	201.96	14.2	14.2	Dedza	TA Kachindamoto	Central
2	34.65945	-14.28770	729.0	173.83	12.5	12.5	Dedza	TA Kachindamoto	Central
3	34.65098	-14.31464	899.0	214.36	10.3	10.3	Dedza	TA Kachindamoto	Central
4	34.66918	-14.27798	980.0	233.68	13.5	13.5	Dedza	TA Kachindamoto	Central
5	34.67547	-14.29677	748.0	178.36	13.5	13.6	Dedza	TA Kachindamoto	Central
6	34.70399	-14.31233	940.0	224.14	13.8	13.9	Dedza	TA Kachindamoto	Central
7	34.66021	-14.31440	750.0	178.83	11.2	11.2	Dedza	TA Kachindamoto	Central
8	34.40480	-14.14309	708.0	168.82	12.6	13.0	Dedza	TA Kasumbu	Central
9	34.37603	-14.16613	855.0	203.87	10.1	10.1	Dedza	TA Kasumbu	Central
10	34.39222	-14.11347	702.0	167.39	13.3	13.6	Dedza	TA Kasumbu	Central
11	34.10195	-13.60131	780.0	196.71	12.1	12.9	Dowa	TA Chiwere	Central
12	34.03334	-13.62131	1075.0	271.11	10.1	10.3	Dowa	TA Chiwere	Central
13	33.91256	-12.86964	990.0	246.99	13.6	13.7	Kasungu	TA Kapelula	Central
14	34.15112	-13.93714	802.0	191.73	12.1	12.1	Lilongwe	SC Chitekwele	Central
15	34.12408	-13.93344	1175.0	280.91	11.7	11.7	Lilongwe	SC Chitekwele	Central
16	34.11306	-13.92603	930.0	222.34	12.4	12.4	Lilongwe	SC Chitekwele	Central
17	34.06626	-13.94075	810.0	193.65	10.4	10.4	Lilongwe	SC Chitekwele	Central
18	33.67695	-13.81103	956.0	228.55	10.1	10.1	Lilongwe	SC Mtema	Central
19	33.88168	-14.23825	778.0	186.00	10.7	10.7	Lilongwe	TA Chadza	Central
20	33.88699	-14.26496	1586.0	379.17	10.6	10.6	Lilongwe	TA Chadza	Central
21	33.39242	-14.14183	1314.0	314.14	10.6	12.2	Lilongwe	TA Chiseka	Central
22	33.55501	-13.79853	770.0	184.08	10.4	10.4	Lilongwe	TA Kabudula	Central
23	33.37140	-14.16159	1764.0	421.72	12.1	12.5	Lilongwe	TA Kalolo	Central
24	33.37945	-13.65575	711.0	169.98	10.0	10.0	Lilongwe	TA Khongoni	Central
25	33.03418	-14.04242	718.8	177.67	15.0	15.0	Mchinji	SC Mavwere	Central
26	33.05347	-14.01936	822.0	203.17	12.2	12.2	Mchinji	SC Mavwere	Central
27	32.73723	-13.60631	1535.0	379.40	17.3	17.4	Mchinji	TA Mkanda	Central
28	32.80760	-13.56557	766.0	189.33	16.4	16.4	Mchinji	TA Mkanda	Central
29	32.86487	-13.56131	766.0	189.33	10.3	10.3	Mchinji	TA Mkanda	Central
30	32.86418	-13.57145	1656.0	409.31	10.7	10.7	Mchinji	TA Mkanda	Central
31	32.78626	-13.58603	1017.0	251.37	17.9	17.9	Mchinji	TA Mkanda	Central
32	32.84890	-13.46520	690.0	170.55	12.6	12.6	Mchinji	TA Mkanda	Central
33	33.76820	-12.24937	720.0	175.86	19.6	19.7	Nkhotakota	SC Kafuzila	Central
34	34.74223	-14.44367	1303.0	314.12	10.5	11.5	Ntcheu	TA Masasa	Central
35	34.72117	-14.34020	866.0	208.77	14.1	14.2	Ntcheu	TA Masasa	Central
36	33.99186	-13.22622	735.0	180.65	12.3	12.4	Ntchisi	SC Nthondo	Central

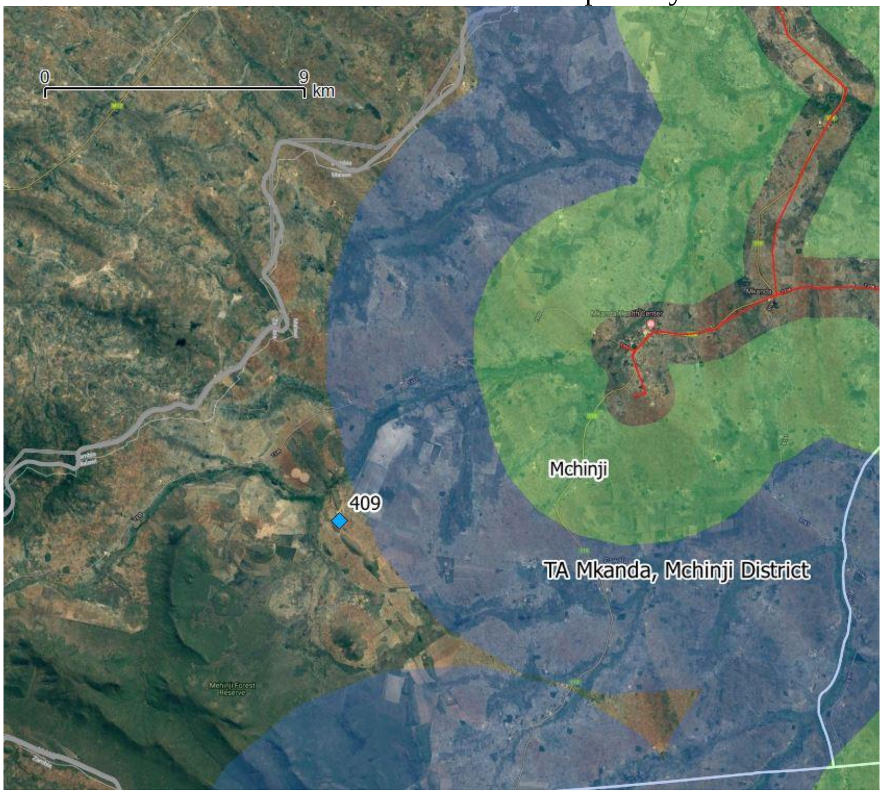
	x	y	Population	Households	km to Grid	km to Trans-former	District	TA / SC	Region
37	34.34640	-13.91687	754.0	183.32	12.3	1.3	Salima	SC Kambwiri	Central
38	34.33306	-13.89964	722.0	175.54	13.0	1.1	Salima	SC Kambwiri	Central
39	34.35112	-13.92687	923.0	224.41	12.1	2.5	Salima	SC Kambwiri	Central
40	33.79408	-12.43733	1158.0	255.23	17.0	17.1	Mzimba	SC Khosolo Gwaza Jere	Northern
41	33.32890	-11.76992	964.0	212.47	16.2	16.2	Mzimba	TA Chindi	Northern
42	33.65945	-12.66256	874.0	192.63	16.0	16.1	Mzimba	TA Mabulabo	Northern
43	33.64806	-12.69770	770.0	169.71	16.2	16.3	Mzimba	TA Mabulabo	Northern
44	33.65584	-12.71937	726.0	160.01	18.0	18.0	Mzimba	TA Mabulabo	Northern
45	33.35862	-11.83177	824.0	181.61	14.8	14.8	Mzimba	TA M'Mbelwa	Northern
46	33.66695	-12.19631	960.0	211.59	14.8	16.6	Mzimba	TA Mzikubola	Northern
47	34.21640	-10.94909	694.8	153.10	13.3	13.4	Rumphi	SC Chapinduka	Northern
48	34.28482	-15.88825	700.0	180.57	19.9	20.1	Chikwawa	TA Chapananga	Southern
49	34.67681	-16.35214	777.0	200.43	12.0	12.0	Chikwawa	TA Ngabu	Southern
50	34.65097	-16.35285	992.0	255.89	14.5	14.5	Chikwawa	TA Ngabu	Southern
51	34.71001	-16.31920	792.0	204.30	10.8	10.8	Chikwawa	TA Ngabu	Southern
52	34.65945	-16.34159	856.0	220.81	13.4	13.4	Chikwawa	TA Ngabu	Southern
53	34.68191	-16.36588	736.0	189.85	10.9	10.9	Chikwawa	TA Ngabu	Southern
54	35.34508	-14.76089	705.0	182.71	12.3	12.3	Machinga	Liwonda National Park	Southern
55	35.43701	-14.79364	1656.0	429.16	10.5	11.0	Machinga	TA Liwonde	Southern
56	35.42793	-14.79020	1074.0	278.33	11.5	11.8	Machinga	TA Liwonde	Southern
57	35.41823	-14.78959	918.0	237.91	12.4	12.4	Machinga	TA Liwonde	Southern
58	35.34473	-14.75020	1317.0	345.40	11.2	11.2	Mangochi	Lake Malombe	Southern
59	34.81640	-14.36617	1406.0	368.75	12.5	12.6	Mangochi	Monkey Bay Urban	Southern
60	35.39788	-14.77155	1056.0	276.95	14.8	14.8	Mangochi	SC Chowe	Southern
61	35.08001	-14.65506	1205.0	316.03	10.8	10.8	Mangochi	TA Chimwala	Southern
62	35.39251	-14.08562	928.0	243.38	11.9	11.9	Mangochi	TA Katuli	Southern
63	34.88123	-13.70779	801.0	210.07	17.7	17.7	Mangochi	TA Makanjila	Southern
64	34.90084	-13.70159	1444.0	378.71	15.6	15.7	Mangochi	TA Makanjila	Southern
65	34.94958	-13.68908	2420.0	634.68	10.6	10.6	Mangochi	TA Makanjila	Southern
66	34.85681	-13.55381	927.0	243.12	26.7	26.7	Mangochi	TA Makanjila	Southern
67	34.89279	-13.70242	1674.0	439.03	16.5	16.5	Mangochi	TA Makanjila	Southern
68	34.92501	-13.68853	1047.0	274.59	13.2	13.2	Mangochi	TA Makanjila	Southern
69	34.88615	-13.70531	1107.0	290.33	17.2	17.2	Mangochi	TA Makanjila	Southern
70	34.93751	-13.69020	2809.0	736.70	11.9	11.9	Mangochi	TA Makanjila	Southern
71	34.85918	-13.62464	1030.9	270.38	22.2	22.3	Mangochi	TA Makanjila	Southern
72	34.85496	-13.58872	1206.3	316.36	24.6	24.6	Mangochi	TA Makanjila	Southern
73	34.81501	-14.34909	710.0	186.21	10.7	10.7	Mangochi	TA Nankumba	Southern
74	34.78834	-14.44603	745.0	195.39	14.8	14.9	Mangochi	TA Nankumba	Southern

Table 13 below provides additional information on the eight off-grid "pre-electrification" candidate sites that also passed the second screening which selected those sites from the initial list within 1 km of a health centre or dispensary. While the list of sites is numbered, this is intended only for identification, not to indicate priority ranking. Maps and descriptive information for each of these eight sites is provided in the following pages of this Annex.

Table 13: Sub-set of 8 off-grid "pre-electrification" candidate locations meeting a second selection criterion: within 1 km of a health centre or dispensary.

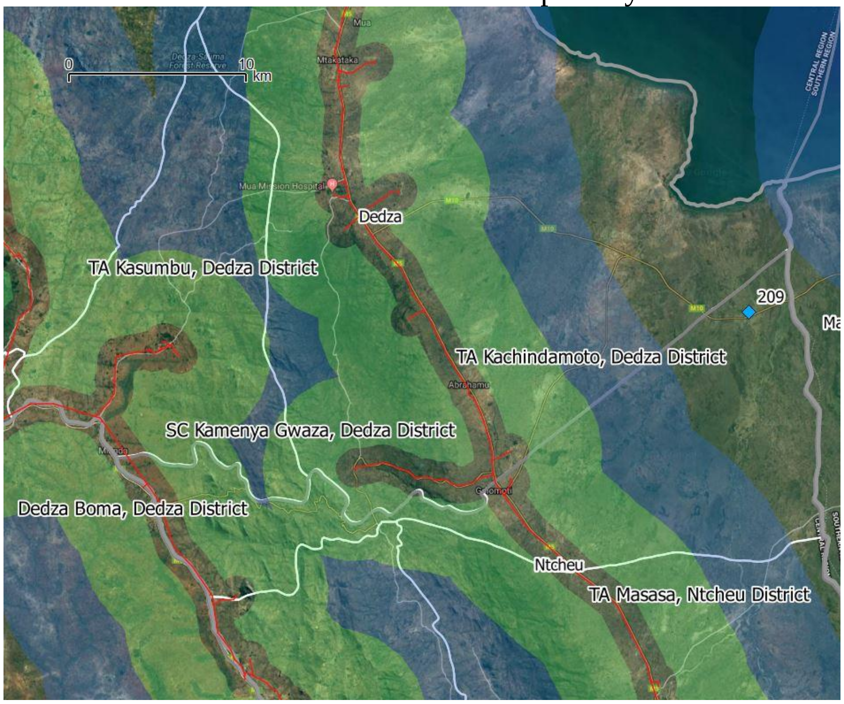
	x	y	Dist. to Grid Line (km)	Traditional Authority / Sub-Chief Name	District	Region	2018 HH Est.	Dist. to Health Facility (m)	Nearby Health Facility Name & Type
1	32.864180	-13.571450	10.7	TA Mkanda	Mchinji	Central	409	441	KAZYOZYO Dispensary
2	34.721170	-14.340200	14.1	TA Masasa	Ntcheu	Central	209	537	PHANGA Dispensary
3	34.124080	-13.933440	11.7	SC Chitekwele	Lilongwe	Central	281	324	CHIMBALANGA Health Centre
4	33.794080	-12.437330	17.0	SC Khosolo Gwaza Jere	Mzimba	Northern	255	433	KHOSOLO Health Centre
5	33.358620	-11.831770	14.8	TA M'Mbelwa	Mzimba	Northern	182	531	KAMTETEKA Health Centre
6	34.816400	-14.366170	12.5	Monkey Bay Urban	Mangochi	Southern	369	786	NANKUMBA Health Centre
7	34.925010	-13.688530	13.2	TA Makanjila	Mangochi	Southern	275	844	LULANGA Health Centre
8	35.437010	-14.793640	10.5	TA Liwonde	Machinga	Southern	429	256	MANGAMBA Health Centre

1) TA Mkanda, Mchinji District, Central Region
    - 409 Households
    - 10.7 km from existing grid lines
    - 441 m from KAZYOZYO Dispensary

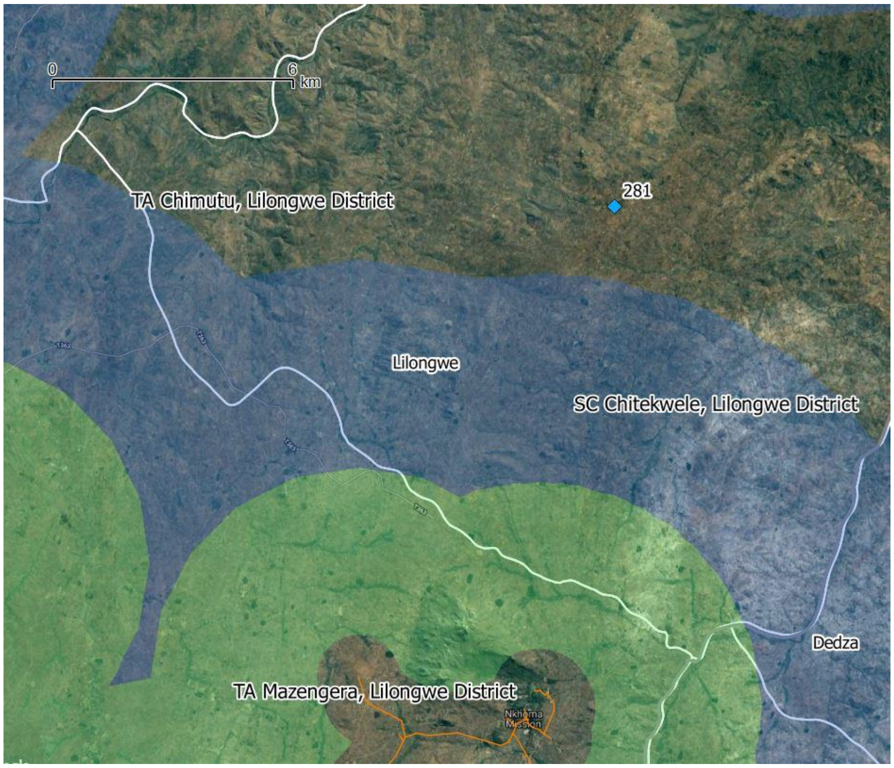


2) TA Masasa, Ntcheu District, Central Region

- 209 Households
- 14.1 km from existing grid,
- 537 m from PHANGA Dispensary

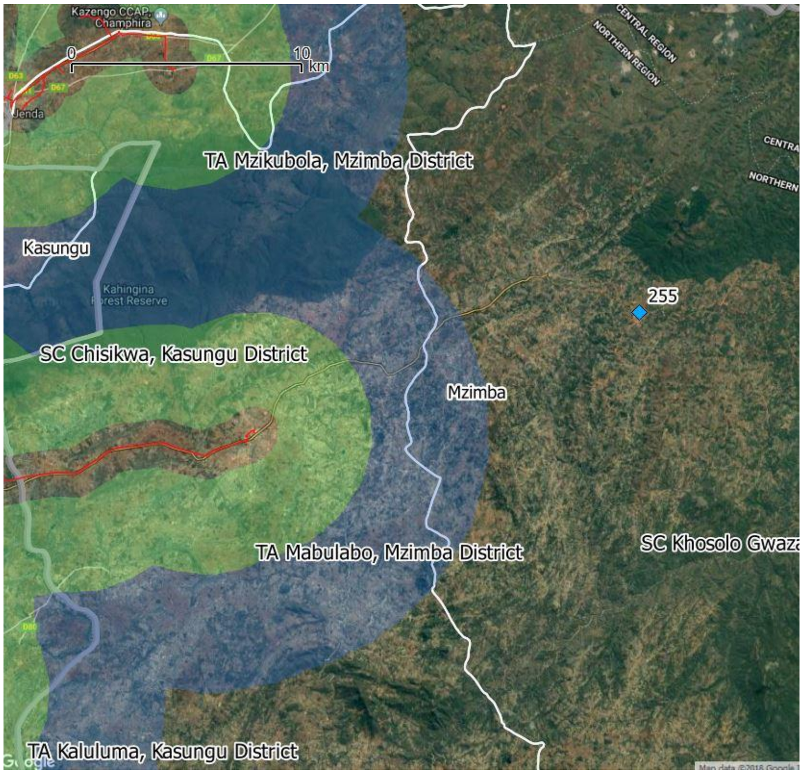


3) SC Chitekwele, Lilongwe District, Central Region
   - 281 Households
   - 11.7 km from existing grid
   - 324 m from CHIMBALANGA Health Centre



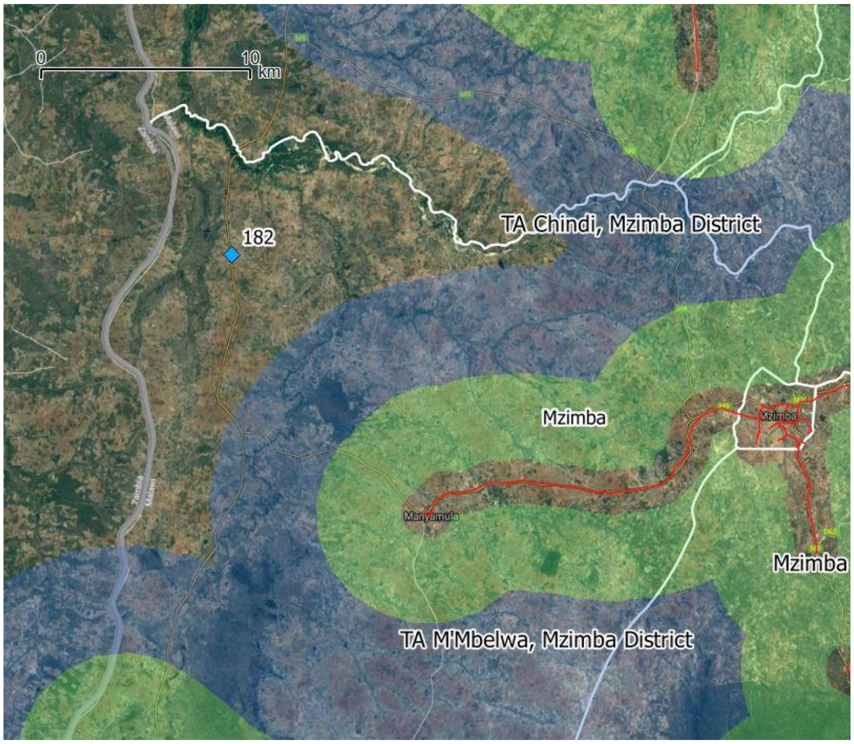
4) SC Khosolo Gwaza Jere, Mzimba District, Northern Region

- 255 Households
- 17.0 km from existing grid
- 433 m from KHOSOLO Health Centre



MILLENNIUM PROMISE™

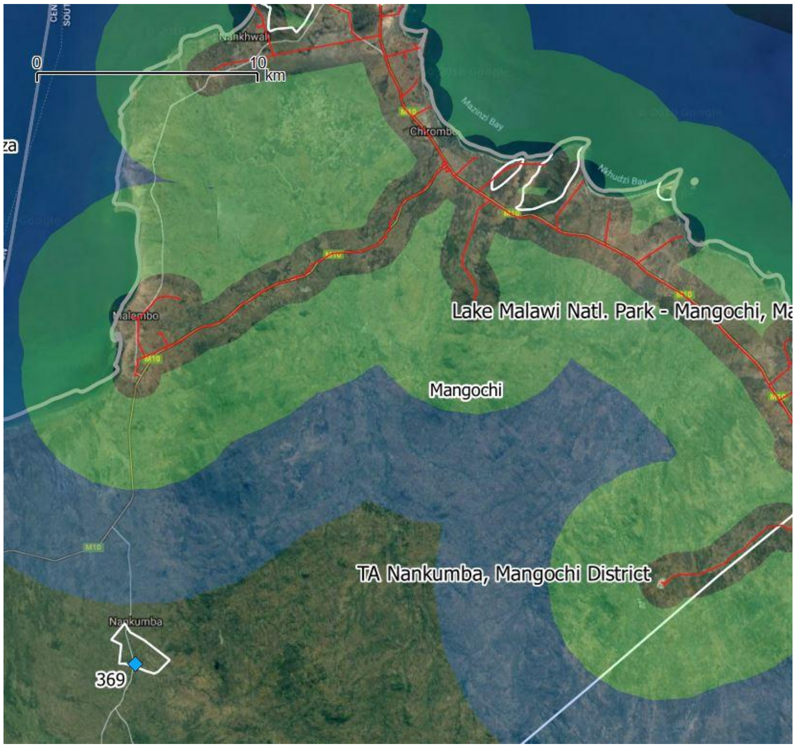
5) TA M'Mbelwa, Mzimba District, Northern Region
   - 182 Households
   - 14.8 km from existing grid lines
   - 531 m from KAMTETEKA Health Centre



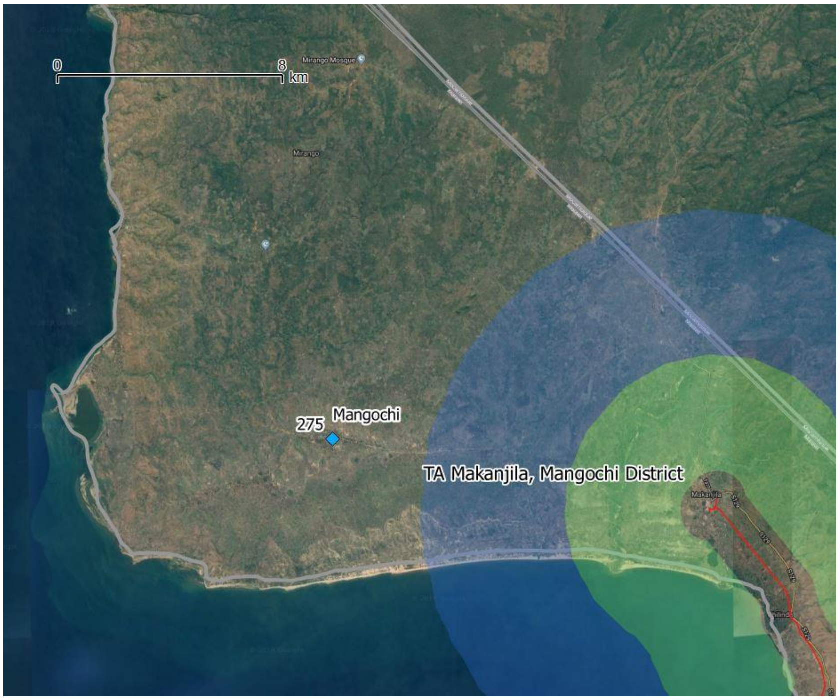
6) Monkey Bay Urban, Mangochi District, Southern Region

MILLENNIUM PROMISE

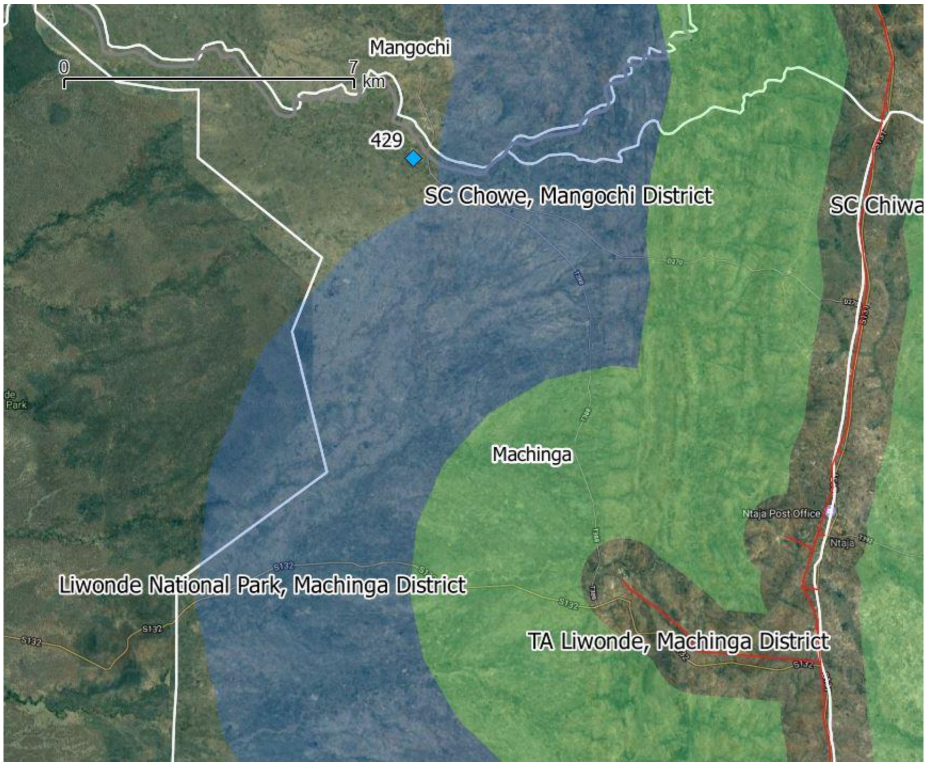
- 12.5 km from existing grid
- 369 Households
- 786 m from NANKUMBA Health Centre

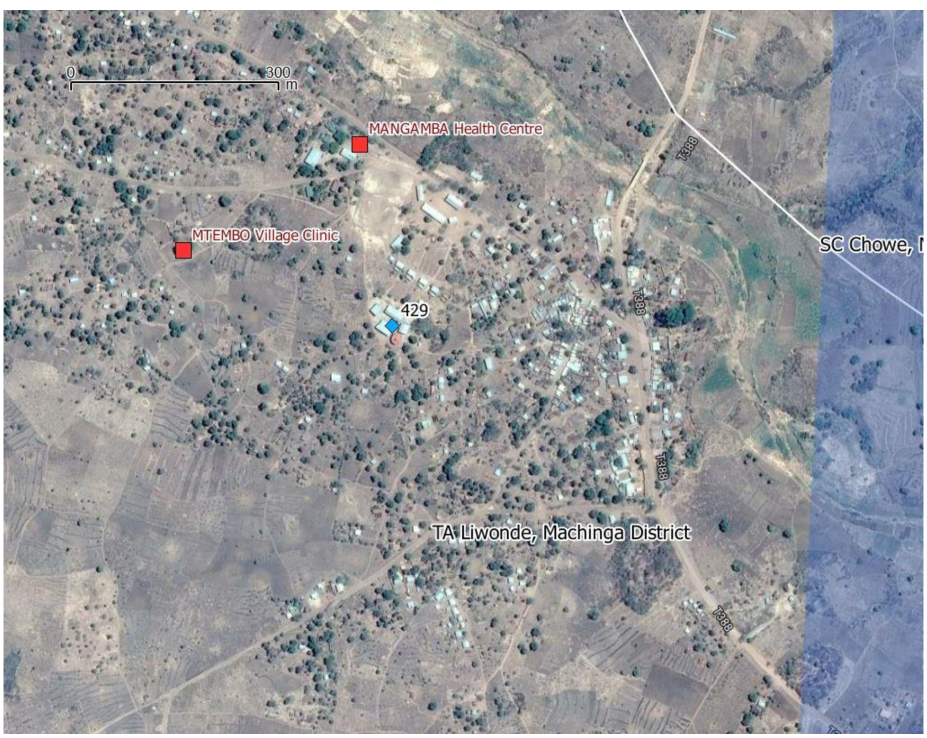


7) TA Makanjila Mangochi District, Southern Region
   - 13.2 km from existing lines
   - 275 Households
   - 844 m from LULANGA Health Centre



8) TA Liwonde, Machinga District, Southern Region
   - 10.5 km from existin grid
   - 429 Households
   - 256 m MANGAMBA Health Centre





Annex E: Off-grid Cost Analysis

(Note: Comparative modeling for this section was performed using Excel workbooks that were provided, along with cost input data, to attendees to the July 2018 Lilongwe training.)

Introduction: Purpose and Background of Mini-Grids in Malawi

The purpose of this analysis has been to establish quantitative estimates for several parameters related to cost modelling for off-grid systems, including generation, storage, distribution, and management per system and per household, noting which values are based on information from within Malawi vs. other countries. This off-grid electrification analysis also provides a first-order assessment of the conditions (e.g. population density and energy consumption per household) that justify electrification via mini-grids versus competing technologies (grid expansion and stand-alone solar). This section includes a summary of information collected from site visits, interviews with experts and companies in the sector, and interviews with government officials, followed by costing analysis.

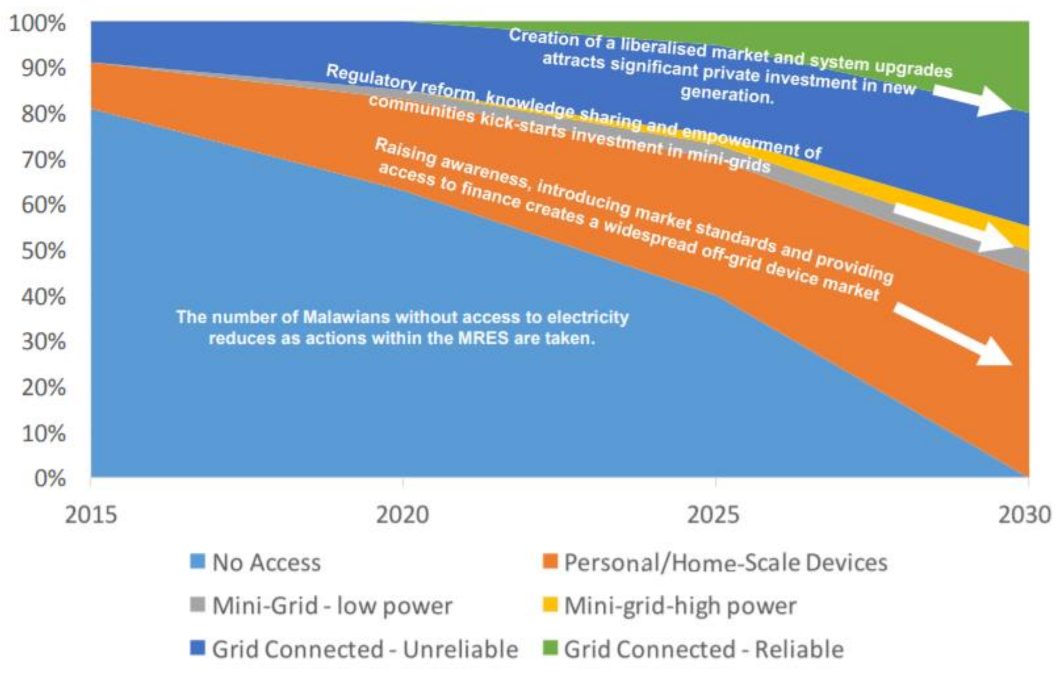


Figure 20: Vision for Electricity Access Rates in Malawi to 2030[4]

[4] Renewable Energy Strategy, March 2017

The current electricity access rate for Malawi is 23%, including 10% of homes connected to the national grid[5] and another 13% with access to an off-grid solar device.[6] Among projections for the future, the Renewable Energy Strategy (2017) stipulates a target of at least 50 mini-grids to be operational by 2025, and the Malawi Action Agenda 2030 on Energy proposes that 900 electricity consumers per year be connected to mini-grids until 2030. However, thus far, there is limited experience of mini-grids in Malawi (see Table 14) and lessons are mixed.

Table 14: Existing mini-grids in Malawi

Mini-grid	Technology and size	Investment and operation	Comments
Mulanje Energy Generation Agency (MEGA)	88 kW micro-hydro based mini-grid, ~580 customers. 3 km from grid.	~ $ 0.8 million from OFID, SG, PA. Implementation support from PA, MuREA, SE. Operation by MEGA.	• commissioned in 2015, remains operational, with plans for expanded generation and network • may connect to grid in the near future
Practical Action / CARD irrigation schemes and mini-grids	4 Solar PV irrigation schemes in Nsanje & Chikwawa districts. Nyamvuu mini-grid (30 kWp) supplies a school, clinic, energy kiosk and trading centre.	Investment of ~$0.85 million (EU grant) by PA/CARD. Operation of the scheme will be delegated to a community organisation.	• commissioned in March 2018. • consumers are too scattered to justify the network
Sitolo mini-grid (CEM/UNDP) (under implementation)	Solar PV mini-grid to serve Sitolo (1st phase 45kWp for 150 HH); 2nd phase to serve nearby villages (80 kWp for 800 HH). 23km from grid	First phase will commence with $250,000 grant from Community Energy Scotland	Designed by CEM and Mzuzu University, procurement on-going, commissioning expected before end 2018.
ESCOM diesel mini-grids	750 kW diesel mini-grid at Likoma island; 300 kW diesel grid at Chizumulu island	Owned and operated by ESCOM; customers pay ESCOM's uniform tariff	
Wind-Solar Hybrid mini-grids (DEA) in 6 sties: • **Northern:** Mzimba, Nkhata-Bay • **Central:** Nkhota-Kota, Ntcheu • **Southern:** Chiradzulu, Thyolo	Systems served 150 households on average and had a standardised specification of 21 kW of generation capacity with 13.1 kW Wind Electricity Generators (WEG) & 7 kWp Photovoltaic (PV).	Village level committees were established by DEA for management with initial support provided by the supplier.	The technology choice was considered appropriate, but tariff collections have not been regular. 5 of 6 systemshave failed at the stage of major repair or battery replacement due to insufficient revenue.

Data collection

[5] ESCOM, 2016

[6] Business Innovation Facility, 2016

Data collection for this analysis included research on existing mini-grids in Malawi, including site visits to a few sites listed in Table 14 above (MEGA, Mchinji, and Nsanje). Suppliers of off-grid solar energy products and contractors were interviewed to collect information on costs of equipment, labour, transport, etc. specific to Malawi. Data collected was complemented with international benchmarks.

Site visit: Mulanje Energy Generation Agency (MEGA)

The Mulanje Energy Generation Agency (MEGA) is a micro-hydro scheme with 88kW of installed capacity, currently serving about 580 customers, including schools, a health centre, maize mills and households[7].

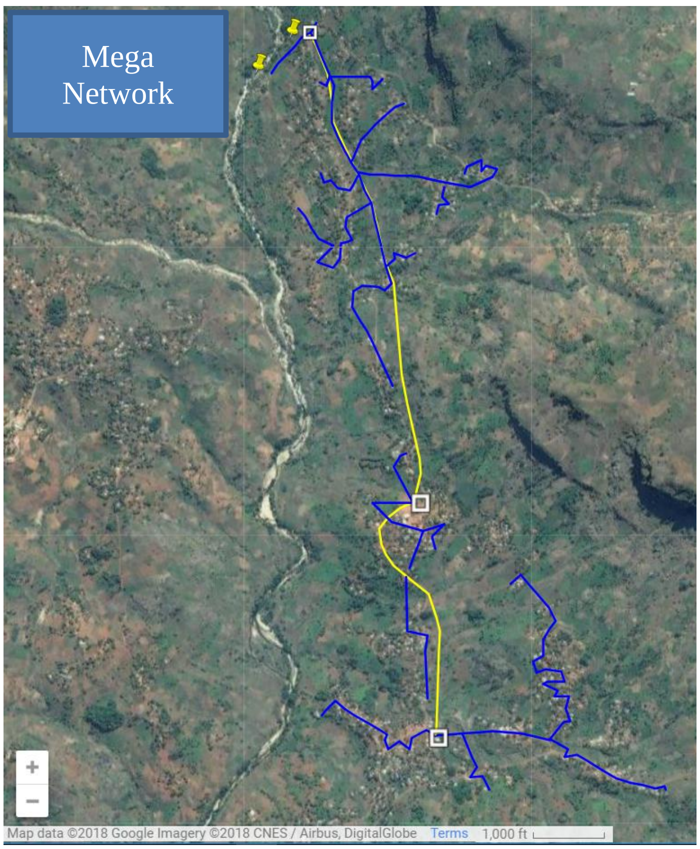


Figure 21: MEGA mini-grid (yellow = MV; blue = LV; Source: MEGA)

It was commissioned in 2015 and constructed with financial support from OFID, SG, and PA[8] (~US$0.8 million[9]). The mini-grid network consists of medium voltage (11 kV)

[7] Interviews, March 2018
[8] https://practicalaction.org/mega-malawi
[9] UNDP report

transmission and five transformers distributing three-phase power at 400 V. The transformers are strategically placed at centres in the village (Bondo has a relatively high population density). The powerhouse is 8 km from the national grid, but the mini-grid extends to within 3km at the closest point. A second generator of around 100kW will be installed. Grid densification and extension is ongoing. There are 3,000 potential HH customers in the coverage area, and it is estimated that 30% of these are concentrated in clusters, while the remaining 70% are more scattered. All of these will eventually be connected to the grid, as funding is made available. MEGA has been issued both a Generation and a Distribution license from MERA and is compliant with national grid codes. Each customer has a pre-payment meter and top-ups up with tokens from MEGA's vending system. The tariff is higher than from ESCOM (44 MKW/kWh to households and 78 MKW/kWh to businesses)[10].

Site Visit: Nsanje irrigation schemes

Practical Action and CARD are supporting irrigation schemes in the Nsanje district. A site visit was conducted to the Nyamvuu scheme, which includes a mini-grid supplying a school, a health centre, a few businesses and an energy kiosk. The project was constructed by local firm FISD and commissioned in March 2018. The total project cost was approximately $350,000[11]. The mini-grid is powered by a 30 kWp solar PV system. 25.5 kWp are dedicated to irrigation and 4.5 kWp are fed to the network that reaches the school and a small trading centre. The powerhouse is located 6km from the main road and from the national grid. The network has 4km of 11kV single phase backbone with two branches. One reaching the school (connecting classrooms and staff housing) and the other the trading centre (energy kiosk, health centre and two shops). Unlike the MEGA scheme, houses around the Nyamvuu scheme are very scattered, making the densification of the grid difficult and costly. There are 14 villages and approximately 800 households in the catchment area.

[10] MEGA website : http://www.mega.mw/technology

[11] The total cost of the irrigation schemes was $853,000. This includes the Nyamvuwu scheme as well as another three 15kWp sites.

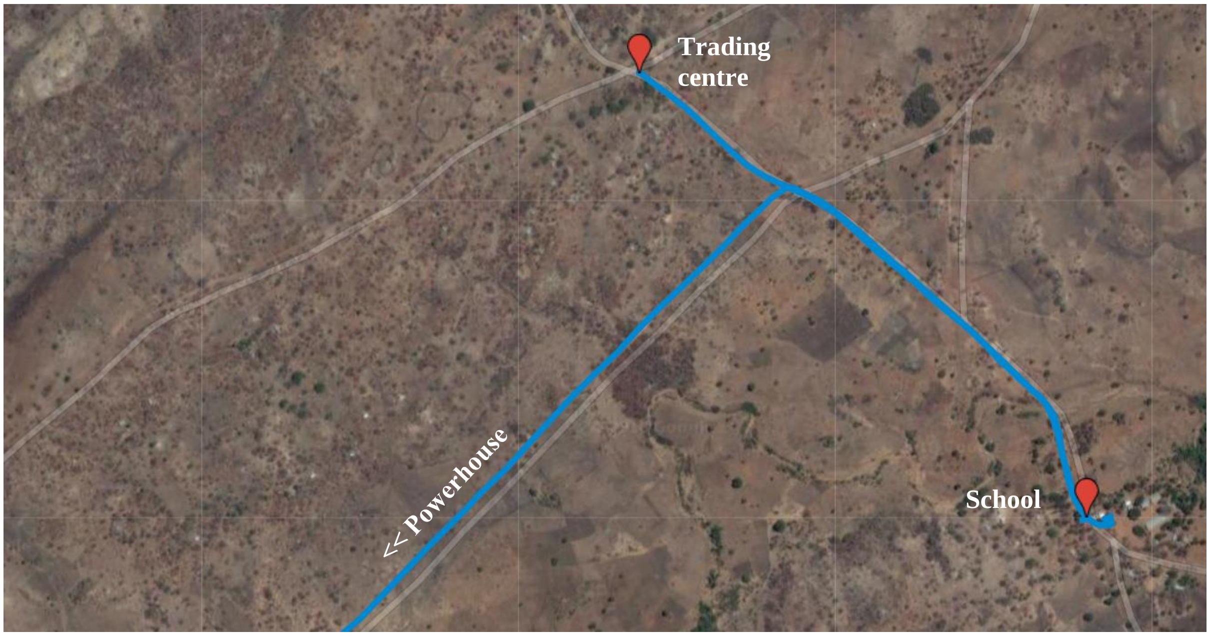


Figure 22: A portion of the Nyamvuwu scheme's network

Site Visit: Mchinji mini-grids (CEM/UNDP)

This mini-grid project in Mchinji district is being developed by Community Energy Malawi (CEM) with support from UNDP. The design has been completed and the project is currently in the procurement phase. It is expected to be commissioned before end 2018. The first phase of the project will be funded through a $250,000 grant. The project targets 4 villages and 900 households in three different phases. The first phase is a mini-grid in Sitolo targeting 100 households and a few businesses and community facilities through a 45 kWp solar PV system. The mini-grid is located 23km from the national grid. Approximately 7.5km of LV network will be used to connect the 120 customers of phase 1. The mini-grid will be managed by CEM. A tariff of about 0.60 $/kWh has been estimated based on offset costs of kerosene and disposable batteries. As shown in Figure 23, Sitolo is densely populated. Similarly, the other 3 villages that are part of the larger project are also densely-populated clusters, each of them a few kilometres apart from each other:

- Ndawambe: 400 HH (phase 2)
- Molosiyo: 400 HH (phase 3)
- Chisenga: 1500 HH (phase 3)

Figure 23: Sitolo (Mchinji District mini-grid site)

Key mini-grid metrics from site visits

The tables below include, for each of the mini-grid sites visited, parameters of power generation capacity, storage, distribution network and connections. This comparison provides a reference for the characterisation of mini-grids in a later stage of the analysis.

Table 15: Population settlement patterns in the visited areas

Project	MEGA	Nsanje	Mchinji
Pattern	Clustered	Scattered	Clustered
Population in catchment area (hh)	3,000	800	2,500
Total surface catchment area (km2)*	10	4	10
Population in clusters (hh)			300 (Sitolo)
Total surface population clusters (km2)			0.24 (Sitolo)
Average population density (hh/km2)	*300*	*200*	*250*
Cluster density (hh/km2)			*1,263*

** Very rough estimation*

Table 16: Comparison of key metrics from mini-grid site visits

Project	MEGA	Nsanje	Mchinji
Power source	Hydro	Solar PV	Solar PV
Installed capacity (kW)	80	4.5*	45
Power generation (kWh/mo)	23,040	540	5,400
Battery storage capacity (kWh)	-	125	792

Project	MEGA	Nsanje	Mchinji
Power consumption (kWh/mo)	20,300	486	4,860
Length of MV (11kV) network (km)	8.5	4	-
Length of LV (220V) network (km)	11	1	3
Average length of service drop (m)	35	Included above	45
Number of customers	580	10	120
Type of customers	570 HHs, 2 schools, health centre, 2 mills	School + quarters, clinic, energy kiosk, 2 shops	100 households, school, clinic, mill
Average consumption per connection (kWh/customer/mo)	*35*	*48.6*	*40.5*
Autonomy of battery bank (days at 50% DoD)	-	*3.5*	*2.2*
Avg network length per customer (m/customer), excluding service drop	*34*	*500*	*25*

**Only considering the portion of the solar PV system that is connected to the mini-grids. The remaining 25.5 kWp are directly connected to irrigation pumps as a separate unit.*

Assessing mini-grid costs

The following pages present technical and cost insights gained from interviews with experts and practitioners in the sector.

Technology costs: Solar PV systems (generation, storage, distribution)

- Average cost of off-grid solar PV in Malawi is $5,700/kWp (with storage, installed). This is 65% higher than a benchmark calculated based on mini-grids in East Africa (Kenya and Rwanda). However, according to solar PV installers, the cost in Malawi could be almost halved when using lower quality equipment.
- In the sites visited, battery storage was substantially larger in the Malawi mini-grids than in the benchmark. Comparing unit costs, Malawi solar PV costs ($/kWp) and battery costs ($/kWh) where between 40-50% higher than the benchmark.

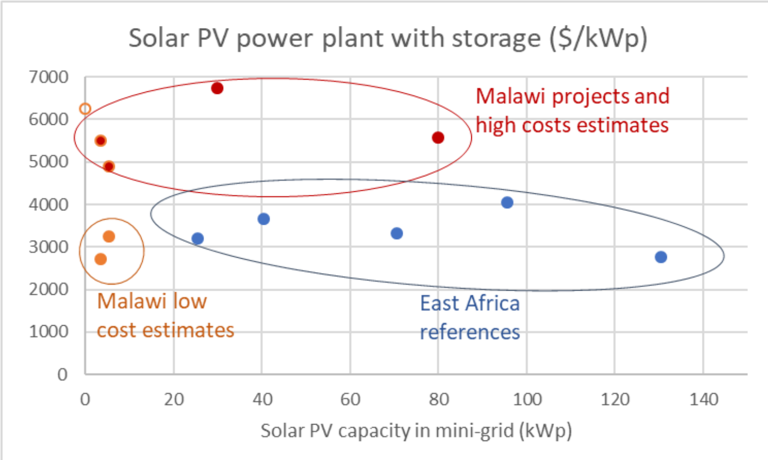


Figure 24: Costs for Solar PV power plant with storage ($/kWp) in Malawi and elsewhere

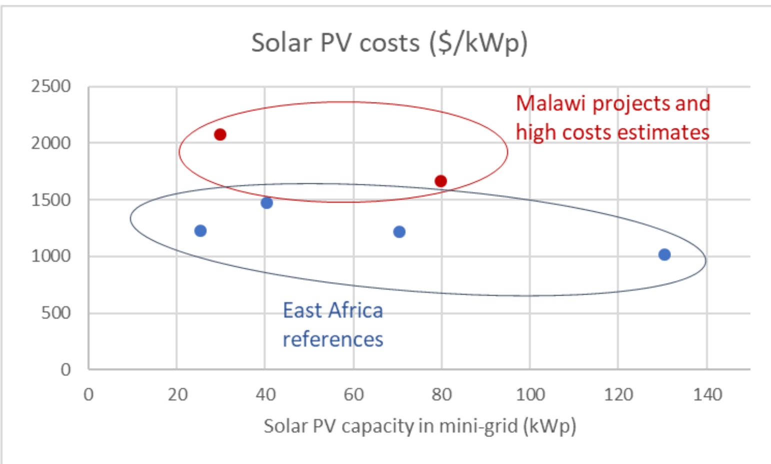


Figure 25: Costs for solar PV modules ($/kWp) in Malawi and elsewhere

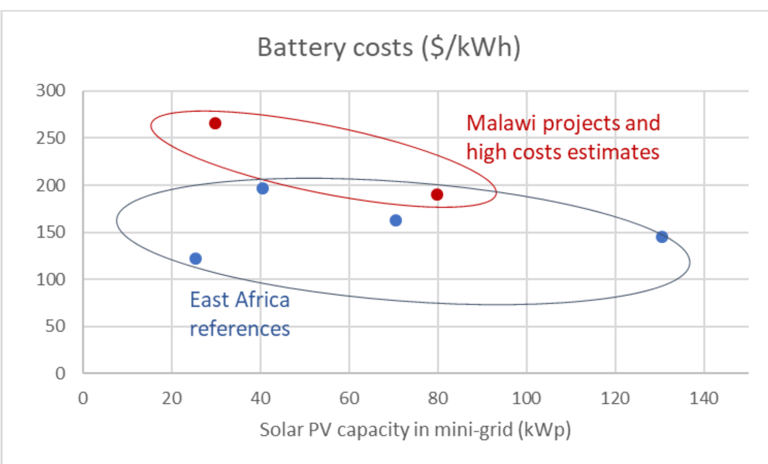


Figure 26: Costs for batteries ($/kWh) in Malawi and elsewhere

Table 17: Average costs for modelling (in USD for equipment installed)

	East Africa projects	Malawi projects	Malawi (low end)	Malawi vs East Africa	Used for modelling*
Solar PV generation (w/ structure & inverters) ($/kWp)	1,252	1,869	n.a.	49%	1,600
Battery bank ($/kWh)	159	227	n.a.	43%	200
Total solar installation, incl BOS ($/kWp)	3,443	5,697	3,037	65%	4,600

**Rounded average of EA cost and Malawi cost*

Table 18: Cost of distribution networks, per unit, installed

Item	Type	International benchmarks	Malawi	High	Low
MV line 3 phase ($/km)	Wood poles, AAAC or ACSR	19,367	11,214		
Transformers ($/kVA)	33kV/400V	77	78		
LV line 3 phase ($/km)	Wood poles, AAC or ABC	15,376	9,298	21,750	7,559
LV line single phase ($/km)	Wood poles, AAC or ABC	5,624	6,406	7,256	4,256
LV 3p backbone and 1p distribution ($/km)*	Wood poles, AAC or ABC	8,549	7,273	11,604	5,246
Single phase service drop ($/connection)	incl meter	192	185	285	106

** Assumption of 30% 3p and 70% 1p*

Affordability and willingness to pay (and relation to energy demand)

	Tier-1	Tier-2	Tier-3	Tier-4	Tier-5
Attributes of electricity access	Electric lighting + radio	Multi-bulb lighting + television	Tier-2 + air cooling (fans), light mechanical	Tier-3 + refrig. + heavy mech. + space heating	All applications feasible
Peak Available Power (W)	> 3W	> 50W	> 200W	> 800W	> 2,000W
Consumption (kWh/year)	> 4.5	> 73	> 365	> 1,250	> 3,000
Duration of supply	> 4 hours	> 4 hours	> 8 hours	> 16 hours	> 23 hours
Evening supply	> 1 hours	> 2 hours	> 3 hours	> 4 hours	> 4 hours
Quality and reliability	Low	Low	Adequate	Max 14 disruptions/week	Max 3 disruptions/week
Technologies that can deliver the attributes	Solar lanterns	Home System	Mini-grids with poor supply; limited grid access	Unreliable grid with limited supply	Reliable grid with 24-hour supply

Affordability and WTP figures will be useful in determining energy demand in off-grid areas in future analyses with more detailed filed assessments. For this preliminary exercise however, energy demand will be estimated using the multi-tier framework for energy access, and mini-grids will be modelled to provide services between Tier 2 and Tier 3. In a next iteration, energy demand can be estimated/cross-checked with ATP/WTP data from existing studies by the NSO and solar lighting market study.

Mini-grids framework in Malawi

The development of the mini-grids framework is led by MERA. Features of draft framework include:

- Various ownership models allowed (public, private, PPP, community-based, etc.)
- Two procurement approaches: solicited mini-grids (government tenders), presumably for priority sites per the Rural Electrification Master Plan, and unsolicited proposals
- Cost-reflective tariffs are allowed
- Mini-grids will require licenses from the government to operate. However mini-grids under 50kW may be exempted (only registration required)
- Presents basic scenarios for mini-grids that get connected to the main grid: a) continue operation as grid-connected mini-grid or b) compensation in case the mini-grid is incompatible (needs development)

The draft framework takes into consideration best practices in the region. On the one side it acknowledges the need for a light-handed regulatory approach for small projects, while on the other it recognises the need for stricter standards and oversight for larger projects. One approach to addressing this situation is to consider different standards for mini-grids of different size or capacity. An example of such a framework is presented in Table 19:

Table 19: a sample framework for differentiating mini-grid standards by system size.

Regulation category	**A**	**B**	**C**
Installed capacity (ex.)	< 100 kW	100 – 1000 kW	> 1000 kW
Licensing requirement	Registration only	Simple permit	License
Tariff level	Cost-reflective	Cost-reflective	Universal
Regulator review	No	Yes	Yes

Regulation category	A	B	C
Returns set by	Investor	Regulator	Regulator
Grid interconnection	No guarantee	Should be guaranteed	Guarantee likely
Compensation payable	Difficult to assess	Pre-determined by regulator	Pre-determined by regulator

It is important to consider this type of framework which differentiates between mini-grid types, primarily for the following reasons:

- Impact on energy demand – larger mini-grids, likely to connect to the grid (see type C in table above) will typically have a tariff level similar to that of the main grid. Smaller mini-grids will allow for cost-reflective tariffs which may represent savings versus kerosene or dry-cell batteries but may still be significantly higher than the price of grid electricity. This has a significant impact on energy demand.[12]
- Impact on technology costs – smaller mini-grids, unlikely to connect to the grid in the short/medium term, and with significantly lower energy demand, can adapt their technology to the demand as opposed to having to comply with grid standards. This results in lower costs for distribution networks.

For this reason, two capacity ranges of mini-grids have been modelled (see section on characterisation of mini-grids).

Preliminary conclusions and qualitative comparison

With regards to technology choice:

- Solar PV likely to be the predominant power source for mini-grids. According to interviews with DEA, while hydro is cheaper than solar PV per kWh produced, hydro sites tend to be far from population settlements. Furthermore, in an off-grid context, demand is constrained and systems can rarely make full use of hydro output.
- To get to several population clusters (e.g. MEGA scheme) medium voltage line necessary, whereas the modular nature of solar PV may allow for separate mini-grids in each cluster, thus avoiding the cost of MV lines and transformers.

With regards to system size:

[12] In some countries, private mini-grid tariffs may be 5-10 times higher than the tariff for the (subsidized) grid.

- It is anticipated that most mini-grids likely to be small under 50kW. However, this will need to be validated later on based on a more detailed geospatial analysis.

With regards to population settlement patterns:

- Mini-grids are more suited to areas where population is settled in clusters (e.g. MEGA and Mchinji) rather than sparsely populated (e.g. Nsanje)

Cost-effectiveness of mini-grids

The objective of this analysis is to assess the cost-effectiveness of mini-grids versus competing technologies. Comparison of mini-grids with SHS and grid extension was conducted based on levelized cost of electricity (LCOE), including all CAPEX and OPEX (generation, distribution, administrative costs, etc.). For this purpose, the following steps were followed:

1. Characterisation of mini-grids
2. Costing of mini-grids and competing technologies
3. Modelling of cost of energy

Characterisation of mini-grids

MERA is currently defining a mini-grids framework for Malawi which will include, among others, licensing procedures and technical standards to be followed. These aspects will have an impact on the cost of a mini-grid and thus on their competitiveness. For example, demanding that mini-grid networks follow technical standards similar to those of the national grid, may result too costly for rural areas with low energy demand. Countries with more advanced mini-grid frameworks (e.g. Tanzania, Rwanda, Kenya) have defined different types of mini-grids according to their size, location and level of service they provide. Different standards apply to the different types of mini-grids. We can anticipate that a similar approach will be adopted in Malawi. Therefore, for modelling purposes, will consider two broad types and sizes for mini-grids:

- **Type 1: Isolated mini-grids**. These typically under 50kWp of installed capacity, in isolated locations not planned for grid connection within 10 years. These mini-grids will provide basic access to electricity to most residential customers (Tier 1 and Tier 2) and make higher levels of access available for productive use. The distribution network (typically low voltage only) will be sized according to the needs of the site and will not follow the standards applicable to the national grid.

- **Type 2: Grid-standard mini-grids.** Better suited for larger villages/towns, with higher energy demand, offering a higher tier of electrification (between Tier 2 and Tier 3) and likely to be connected to the grid in the medium term (below 10 years). For this reason, the design of the network will follow similar practices (and incur similar cost) as the national utility, in preparation for grid connection.

Costing Modelling

The costing of both types of mini-grids will be defined based on costs in Malawi and international benchmarks and will include both investment costs and operating costs.

- **Generation costs:** solar PV equipment, battery storage, power conditioning and BOS
- **Distribution costs:** wires and poles
- **Connection costs:** Line drop, circuit breaker, meter, etc.
- **Operating costs:** O&M, administrative costs, replacement of parts (e.g. batteries)
- **Other costs:** engineering, procurement, transport, installation, civil works, etc.

For competing technologies, we will assess cost of solar home systems and the cost of grid extension, including both CAPEX and OPEX.

Table 20: Costs for example mini-grids, Types 1 and 2

Cost component	Type 1 mini-grid	Type 2 mini-grid	Comments
Energy demand per HH (kWh/mo)	6 (Tier 2 lower threshold)	12 (higher end of Tier 2)	
Productive uses (maize mills, water pumping, etc.)	No	Yes	
Solar PV generator (incl structure and solar inverters) ($/kWp)	1,600		
Battery bank ($/kWh)	200		Storage sized at 1 day of autonomy at 50% DoD
Power conditioning and BOS ($/kWp)	800		
Total solar equipment ($/kWp)	***4,600***		

Cost component	Type 1 mini-grid	Type 2 mini-grid	Comments
Energy demand per HH (kWh/mo)	6 (Tier 2 lower threshold)	12 (higher end of Tier 2)	
Productive uses (maize mills, water pumping, etc.)	No	Yes	
Solar PV generator (incl structure and solar inverters) ($/kWp)	1,600		
LV network ($/km) 3-phase backbone with single phase distribution to households	5,000	8,000	Cost of network serving low demand vs cost of grid-standards network
Single phase service drop ($/connection)	100	200	
O&M costs (% of capex p.a.)	1.5%		
Administrative costs ($/customer/a)	20		

Costs of two alternative technologies will also be compared to mini-grids:

- Grid extension: cost of MV network at $15,000 per km and transformer at $80/kVA
- SHS: $7-8 per Wp depending on size of system

Cost-effectiveness analysis

The cost effective analysis (performed with excel models) determines **Levelized Cost Of Electricity (LCOE) of mini-grids versus solar home systems and grid extension**, given costs of each technology (per section above) and the following key variables:

- Energy consumption per customer
- Density of customers (meters of network required, per customer)
- Distance to the grid connection point

These factors are critical in determining what conditions have to be met for mini-grids (both for type 1 and type 2) to be viable versus competing technologies.

Preliminary conclusions of cost modelling

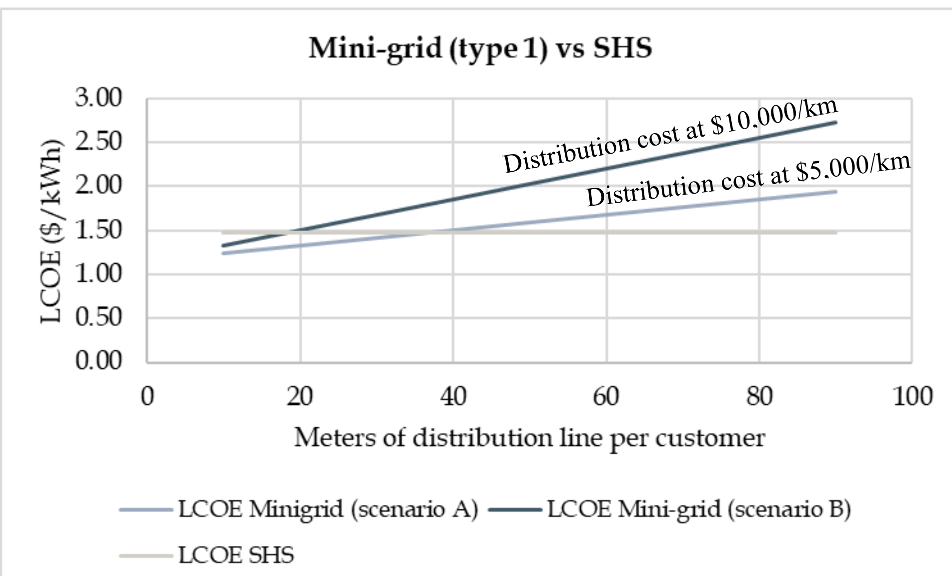
Type 1 mini-grids

This model compares:

- 26kWp solar PV mini-grid serving 400 customers (90% of which are households consuming 6kWh/month). There are also businesses and institutions with low energy consumption (e.g. hair dressers, general stores, cinema, etc.). The network is built below grid standard, commensurate with the low level of electricity demand.
- SHS for said 400 customers (50Wp units for households, 130 Wp for businesses and institutions), adding up to about the same total PV capacity as the mini-grid
- Cost of extending the MV network (33 or 11kV) to the site and supplying electricity at the grid cost

Results:

- Against SHS, the mini-grid has a lower cost (on a levelized basis) if the density of customers is such that the distribution network (excluding service drops) is no longer than 40 meters per customer (25 customers per km of distribution network). This is approximately equivalent to a density of 500-600 customers per square kilometre.
- Against extension of the grid, the mini-grid has a lower cost (on a levelized basis) if the MV network is further than 10 kilometres.



Type 2 mini-grids

This model compares:

- 100kWp solar PV mini-grid serving 600 customers (90% of which are households consuming 12kWh/month) and substantial energy demand from productive uses (40% of demand from businesses and institutions incl maize mills, water pumping, welding, refrigeration, etc.). The network is built to grid standard at a cost of $8000/km and $200 per connection.
- SHS for said 600 customers (100Wp units for households, 625 Wp for businesses and institutions), adding up to about the same total PV capacity as the mini-grid
- Cost of extending the MV network (33 or 11kV) to the site and supplying electricity at the grid cost

Results:

- Against SHS, the mini-grid has a lower cost (on a levelized basis) if the density of customers is such that the distribution network (excluding service drops) is no longer than 30 meters per customers (33 customers per km of distribution network). This is approximately equivalent to a density of 700-800 customers per square kilometre.
- Against extension of the MV grid, the mini-grid has a lower cost (on a levelized basis) if the MV network is further than 40 kilometres.

Overall conclusions

Solar PV mini-grids can, under certain circumstances, offer lower cost of electricity than solar home systems (SHS), diesel mini-grids or the extension of the grid to remote communities. Mini-grids are a cost-effective solution in general, when:

- Peak power and energy demands are expected to be moderate, under 100 kW and supplying less than 150 MWh a year per mini-grid. Sites with higher demands can be justified if ESCOM grid is not expected to serve that location within 5 years.
- There are many customers per community (e.g., 20 or more), so that there is sufficient electricity demand to justify setting up of the mini-grid infrastructure.
- Customers are in denser communities, (e.g., 500-800 customers/km^2 depending on the type of mini-grid, or more), so that distribution network costs are lessened. Sites like MEGA and Mchinji (Sitolo) are viable in this regard. Nsanje is not.

- Distance from the national grid is 10 to 40 km or more from the community to be served, depending on the energy demand of the site. The higher the energy demand, the more isolated it needs to be for solar PV and batteries to be viable against the national grid.
- There are productive/commercial loads, especially during daytime, permitting the mini-grid network and generation assets to be better utilized. Also, the willingness-and ability-to-pay of productive/commercial customers are higher than domestic customers thus increasing revenues.
- Adding a diesel generation as a back-up power source with solar PV mini-grids is justified as it could be lower cost than increasing capacity of solar PV and batteries to improve year-round electricity availability.

The following are possible steps to refine this cost effectiveness analysis:

- Improve (provide more details) the load profile and system sizing of mini-grids
- More scrutiny or additional information with regards to cost assessment
- Review energy demand assumptions based on NSO expenditure surveys and market assessments for solar lighting (BIF)
- Identify possible mini-grid sites in Malawi and provide rough estimates of energy demand, capacities and cost (perhaps in a later stage of geospatial analysis)